11-21-06

OIPE IAP58 NOV 20 2006 PATENT & TRADEMARK OFFICE

AF

PTO/SB/21 (09-04)
Approved for use through 07/31/2006. OMB 0651-0031
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

Application Number	10/758,740
Filing Date	January 16, 2004
First Named Inventor	Wade Thomas Cathey, Jr.
Art Unit	2872
Examiner Name	Audrey Y. Chang
Attorney Docket Number	414671
Total Number of Pages in This Submission	

ENCLOSURES (check all that apply)

- [x] Fee Transmittal Form
  - [ ] Fee Attached
- [ ] Amendment / Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
- [x] Extension of Time Request
- [ ] Express Abandonment Request
- [ ] Information Disclosure Statement
- [ ] Certified Copy of Priority Document(s)
- [ ] Reply to Missing Parts/ Incomplete Application
  - [ ] Reply to Missing Parts under 37 CFR1.52 or 1.53
- [ ] Drawing(s)
- [ ] Licensing-related Papers
- [ ] Petition
- [ ] Petition to Convert to a Provisional Application
- [ ] Power of Attorney, Revocation Change of Correspondence Address
- [ ] Terminal Disclaimer
- [ ] Request for Refund
- [ ] CD, Number of CD(s) _____
  - [ ] Landscape Table on CD
- [ ] After Allowance Communication to TC
- [ ] Appeal Communication to Board of Appeals and Interferences
- [x] Appeal Communication to TC (Appeal Notice, Brief, Reply Brief)
- [ ] Proprietary Information
- [ ] Status Letter
- [x] Other Enclosure(s) (please identify below):

Certificate of Mailing
Return Post Card

Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm	LATHROP & GAGE LC		
Signature	John L		
Printed Name	John Lindemann		
Date	November 20, 2006	Reg. No.	54,273

CERTIFICATE OF MAILING 37 CFR 1.10

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as Express Mail Post Office to Addressee (Label No. EV498086035US) in an envelope addressed to: Mail Stop: Amendment, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on the date shown below.

Signature	Mike Morgan		
Typed or printed name	Mike Morgan	Date	November 20, 2006

PTO/SB/17 (01-06)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

Fees pursuant to the Consolidated Appropriations Act, 2005 (H.R. 4818).

FEE TRANSMITTAL for FY 2006

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 500

Complete if Known	
Application Number	10/758,740
Filing Date	January 16, 2004
First Named Inventor	Wade Thomas Cathey, Jr.
Examiner Name	Audrey Y. Chang
Art Unit	2872
Attorney Docket No.	414671

METHOD OF PAYMENT (check all that apply)

☐ Check ☐ Credit Card ☐ Money Order ☐ None ☐ Other (please identify) : ____

☒ Deposit Account Deposit Account Number: 12-0600 Deposit Account Name: Lathrop & Gage LC

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☒ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, **except for the filing fee**

☒ Charge any additional fee(s) or underpayments of fee(s) Under 37 CFR 1.16 and 1.17 ☒ Credit any overpayments

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	FILING FEES		SEARCH FEES		EXAMINATION FEES		
		Small Entity		Small Entity		Small Entity	
Application Type	Fee ($)	Fee($)	Fee($)	Fee($)	Fee($)	Fee($)	Fees Paid ($)
Utility	300	150	500	250	200	100	____
Design	200	100	100	50	130	65	____
Plant	200	100	300	150	160	80	____
Reissue	300	150	500	250	600	300	____
Provisional	200	100	0	0	0	0	____

2. EXCESS CLAIM FEES

Fee Description	Fee ($)	Small Entity Fee ($)
Each claim over 20 (including Reissues)	50	25
Each independent claim over 3 (including Reissues)	200	100
Multiple dependent claims	360	180

Total Claims ____ -20 or HP= Extra Claims ____ x Fee($) ____ = Fee Paid ($) ____

HP = highest number of total claims paid for, if greater than 20.

Indep. Claims ____ - 3 or HP= Extra Claims ____ x Fee($) ____ = Fee Paid ($) ____

HP = highest number of independent claims paid for, if greater than 3.

Multiple Dependent Claims: Fee ($) ____ Fee Paid ($) ____

3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper (excluding electronically filed sequence or computer listings under 37 CFR 1.52(e)), the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

Total Sheets ____ - 100 = Extra Sheets ____ / 50 = Number of each additional 50 or fraction thereof ____ (round **up** to a whole number) x Fee ($) = Fee Paid ($) ____

4. OTHER FEE(S) **Fees Paid ($)**

Non-English Specification, $130 fee (no small entity discount) ____

Other (e.g., late filing surcharge) : Appeal Brief $500

SUBMITTED BY

Signature	[signature]	Registration No. (Attorney/Agent)	54,273	Telephone	(720) 931-3018
Name (Print/Type)	John Lindemann			Date	November 20, 2006

OIPE IAP58
NOV 2 0 2006
PATENT & TRADEMARK OFFICE

CERTIFICATE OF MAILING BY EXPRESS MAIL POST OFFICE TO ADDRESSEE (37 CFR 1.10) Inventor(s): Wade Thomas Cathey, Jr., et al.			Matter No. 414671
Serial No.	Filing Date	Examiner	Group Art Unit
10/758,740	January 16, 2004	Audrey Y. Chang	2872

Invention Extended Depth Of Field Optical Systems

I hereby certify that the following: Transmittal Form (1 page); Fee Transmittal For FY 2006 (1 page in duplicate); Petition For Extension of Time Under 37 CFR 1.136(a) (1 page in duplicate); Appeal Brief (78 pages, including 2 page Claim Appendix, 1 page Related Proceeding Appendix and 28 page Evidence Appendix with attachments); authorization to charge $950 ($500 for the Appeal Brief and $450 for the extension fee); authorization to charge additional fees that may be required, or credit any overpayment, to Deposit Account No. 12-0600; and return post card are being mailed in an envelope addressed to: Mail Stop: Appeal Brief -- Patents, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on this 20th day of November, 2006.

Mike Morgan
Name of Depositor

Mike Morgan
Signature of Depositor

EV498086035US
Express Mail Label No.

PATENT
Attorney Docket No.: 414671
Express Mail Label No.: EV498086035US

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

Appellant(s)	Wade Thomas Cathey Jr. et al.	Examiner	Audrey Y. Chang
Serial No.	10/758,740	Group Art No.	2872
Filed	16 January 2004	Confirmation No.	6369
For	EXTENDED DEPTH OF FIELD OPTICAL SYSTEMS		

November 20, 2006

Mail Stop Appeal Brief – Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

APPEAL BRIEF

Sir/Madam:

In accord with 37 C.F.R. § 41.37, and fully responsive to the office action of 20 March 2006, Appellants hereby file this appeal brief in support of an appeal in the above-identified matter. A notice of appeal, with the appropriate fee of $500 as required by 37 C.F.R. §§ 41.31(a)(1) and 41.20(b)(1), was filed on 20 July 2006. The $500 fee for this appeal brief, as required by 37 C.F.R. § 41.20(b)(2); a petition for a 2-month extension of time; and the $450 fee for the extension of time are submitted herewith. This appeal brief is timely filed within five months of the mailing of the notice of appeal.

(1) Real party in interest.

The real party in interest for this appeal is CDM Optics Inc., a corporation established under the laws of the State of Colorado and having a principal place of business at 4001 Discovery Drive, Suite 130, Boulder, CO 80303, U.S.A. CDM Optics, Inc. is the exclusive licensee of The Regents of the University of Colorado of U.S. Patent Application No. 09/070,969, of which the present application is a continuation. Evidence of assignment of U.S. Patent Application No. 09/070,969 to The Regents of the University of Colorado was recorded on 13 November 2002, and may be found at reel/frame 013475/0712.

(2) Related appeals and interferences.

No other appeals or interferences are currently known to Appellants that will directly affect, be directly affected by, or have a bearing on the decision to be rendered by the Board of Patent Appeals and Interferences in the present appeal.

However, for the sake of completeness, we call the Board's attention to a petition under 37 CFR §1.131(a)(3) that has been entered in U.S. Patent Application No. 09/070,969, to which the present application claims priority and which is pending before the same Examiner. The petition in 09/070,969 concerns the Examiner's refusal to consider references in Information Disclosure Statements which, to the best of Appellants' knowledge, were submitted in full compliance with the governing requirements of 37 CFR §1.97 and §1.98. If the petition in 09/070,969 is granted, it may result in the consideration of references in 09/070,969, and in the present application as provided by MPEP §609.02(A)(2).

(3) Status of claims.

Claims 7, 8 and 11-23 are pending in this application.

Note that claims 7, 8 and 11-23 are "objected to" due to matters of language. On the one hand, the Examiner classifies these issues as "informalities" such that "Appropriate correction is required;" but on the other hand, the Examiner says "the scopes of the claims are not well definite [sic]." Office Action of 20 March 2006,

pages 2-3. Since the Examiner's "objections" touch the merits of the claims, and Office policy[1] requires that such matters be classified as "rejections," Appellants are compelled to respond to these "objections" as "rejections."

Claims 7, 11-14, 16, 18, 20 and 23 stand rejected under 35 U.S.C. §102(b) or 35 U.S.C. §103(a) as anticipated by, or obvious over, U.S. Patent No. 4,480,896 granted to Kubo et al (hereinafter "Kubo").

The Office Action of 20 March 2006 does not clarify which section of 35 U.S.C. claims 7, 11-14, 16, 18, 20 and 23 are rejected under. This Office Action listed a heading of "Claim Rejections - 35 U.S.C. §103," and included a quote from 35 U.S.C. §103(a) just above this rejection, but the rejecting sentence itself says "Claim 7, 11 and newly added claims 12-14, 16, 18, 20 and 23 are rejected under 35 U.S.C. §102(b) as being anticipated by the patent issued to Kubo et al (PN. 4,480,896)." Office Action of 20 March 2006, page 3. However, the Examiner also made statements about what would be "obvious" in this rejection: "Although this reference does not teach explicitly that the optical mask and the lens are integrally formed such modification would have been obvious to one skilled in the art for the benefit of reducing the number of the elements in the photographic system..." Office Action of 20 March 2006, page 5. Appellants noted this inherent contradiction in the Response to Office Action sent via facsimile on 19 May 2006 and responded on the assumption that the rejection was under 35 U.S.C. §103(a). An Advisory Action mailed 9 June 2006 did not clarify this rejection.

Claims 8, 15, 17 and 21 stand rejected under 35 U.S.C. §103(a) as unpatentable over Kubo in view of the article "Optical/Digital incoherent image processing for extended depth of field" by Poon et al. in Applied Optics, vol. 26, no. 21, page 4612, November 1987 ("Poon").

---

[1] "The refusal to grant claims because the subject matter as claimed is considered unpatentable is called a 'rejection.' The term 'rejected' must be applied to such claims in the examiner's action. If the form of the claim (as distinguished from its substance) is improper, an 'objection' is made.." MPEP §706.01, emphasis added.

<u>Claims 19 and 22 are not under any rejection over prior art, yet have not been indicated as allowable subject matter by the Examiner.</u>

Claims 7, 8 and 11-23 stand provisionally rejected under the judicially created doctrine of obviousness-type double patenting as unpatentable over claims 75, 87, 88, 94, 95 and 99 of copending U.S. Patent Application No. 09/070,969 and claim 1 of copending U.S. Patent Application No. 11/192,572, which has now issued as U.S. Patent No. 7,106,510.

Claims 7, 8 and 11-23 stand rejected under the judicially created doctrine of obviousness-type double patenting as unpatentable over claims 1-21 of U.S. Patent No. 5,748,371, over claims 1-4 of U.S. Patent No. 6,783,733, over claims 1-29 of U.S. Patent No. 6,911,638 and over claim 1 of U.S. Patent No. 6,940,649.

Claims 7, 8 and 11-23 stand rejected under the judicially created doctrine of obviousness-type double patenting as unpatentable over claims 1-5 of U.S. Patent Application No. 10/355,761, which has now issued as U.S. Patent No. 7,115,849.

Appellants appeal the rejection of claims 7, 11-14, 16, 18, 20 and 23 under 35 U.S.C. §102(b) and/or 35 U.S.C. §103(a), whichever rejection the Examiner intends (as it remains completely unclear), and the rejection of claims 8, 15, 17 and 21 under 35 U.S.C. §103(a). Appellants also appeal the "objection to" claims 7, 8 and 11-23 insofar as the "objection" is apparently directed to the merits of these claims, as opposed to matters of form. Appellants further request a positive indication as to whether claims 19 and 22 are allowable over the art of record, the Examiner's failure to do so notwithstanding. Appellants believe that no appeal of the double patenting rejections is necessary insofar as allowable subject matter has not been indicated by the Office, and that such rejections may be addressed with one or more terminal disclaimers once allowable subject matter is indicated (a terminal disclaimer now is thereby inappropriate).

(4) <u>**Status of amendments.**</u>

The present application was filed on 16 January, 2004 as a continuation application of a commonly-owned and copending application, 09/070,969 filed 1 May

1998. A first office action in the present application was mailed on 5 November 2004. On 5 May 2005, a response to the first office action was filed and entered. On 8 July 2005, a second, non-final office action was mailed. On 9 January 2006, a response to the second office action was filed and entered. On 20 March 2006, a final office action was mailed. On 19 May 2006, a response to the final office action was filed. On 9 June 2006, an advisory action was mailed. A notice of appeal was filed on 20 July 2006.

Claims 7, 8 and 11-23 are currently pending. Claims 1-11 were filed with the original application. Claims 1, 3, 7, and 9-11 were amended, and claims 4-6 were canceled, in the response filed 5 May 2005. Claims 7, 8 and 11 were amended, claims 1-6 and 9-10 were cancelled, and claims 12 through 23 were added, in the response filed 9 January 2006. No claim amendments were made in the response filed 19 May 2006.

(5) Summary of claimed subject matter.

U.S. Patent Application No. 10/758,740 discloses extended depth of field optical systems (p. 6, [0021], p. 12, [0039], FIG. 2). Subject matter of the independent claims involved in this appeal is as follows:

Claims 7 and 8 are for an imaging system characterized at least by an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function ("PSF") (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is at least a function of the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The optical system comprises at least one lens and an optical mask that cooperate to image light from an object to form an optical image (specification paragraphs **[0071]** - **[0072]** and FIG. 2). The light is

characterized by at least phase (as is known in the art). The optical system comprises a detector for detecting the optical image over a range of spatial frequencies to generate a stored image (detector at specification paragraphs **[0012], [0071]** and FIG. 2; range of spatial frequencies shown in FIG. 10). The optical mask is configured for modifying the phase of the light (specification paragraphs **[0072]** - **[0073]**) such that a main lobe of the ambiguity function is broader in v for a given value of u (compare FIG. 9 with FIG. 4) and the PSF has a functionally different form for a given value of ψ (compare FIG. 20 with FIG. 17), in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values of u and ψ, over an extended depth of focus larger than a depth of focus formed without the optical mask (compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

Claims 11 - 13 are for an imaging system having insensitivity to misfocus, the imaging system being characterized at least by an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function ("PSF") (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is at least a function of the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The optical system comprises at least one lens, an optical mask and a detector that cooperate to image light from an object to form a stored image (specification paragraphs **[0012], [0071]** - **[0072]** and FIG. 2). The lens is characterized by at least a length L, a focal length f, a front principal plane and a rear principal plane, (specification paragraph **[0075]**). The light is characterized by at least phase and a wavelength λ (as is known in the art). The optical mask modifies the phase

(specification paragraphs **[0072]** - **[0073]**) such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u (compare FIG. 9 with FIG. 4) and the PSF has a functionally different form (compare FIG. 20 with FIG. 17), in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ, defined by the equation:

$$\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right),$$

where d_o is a distance from the object to the front principal plane and d_i is a distance from the rear principal plane to the detector (specification paragraph **[0075]**, and compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

Claims 14 and 15 are for a method of imaging, in an optical system characterized by at least an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function (PSF) (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is at least a function of the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The method comprises: (1) imaging light from an object to form an optical image (specification paragraphs **[0071]** - **[0072]** and FIG. 2), which light is characterized by at least phase (as is known in the art); and (2) detecting the optical image to generate a stored image (specification paragraphs **[0012]**, **[0071]** - **[0072]** and FIG. 2). Imaging includes modifying the phase (specification paragraphs **[0072]** - **[0073]**) such that a main lobe of the ambiguity function is broader in v for a given value of u (compare FIG. 9 with

FIG. 4), and the PSF has a functionally different form for a given value of ψ (compare FIG. 20 with FIG. 17) over an extended depth of focus that is larger than a depth of focus formed without modifying the phase, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical system without modifying the phase for those given values of u and ψ (compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

Claims 16 and 17 are for an imaging system comprising a lens and an optical mask that cooperate to image light from an object to form an optical image (specification paragraphs **[0071]** - **[0072]** and FIG. 2) having a range of spatial frequencies that is limited by an aperture (as is known in the art) of at least one of the lens and the optical mask, which light includes at least phase (as is known in the art); and a detector for detecting the optical image over the range of spatial frequencies to generate a stored image (detector at specification paragraphs **[0012]**, **[0071]** and FIG. 2; range of spatial frequencies shown in FIG. 10). The imaging system is characterized at least by an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function (PSF) (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is at least a function the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The optical mask is configured for modifying the phase without reducing the range of spatial frequencies (compare the spatial frequency range shown in FIG. 10 to that shown in FIG. 6) such that a main lobe of the ambiguity function is broader in v for a given value of u (compare FIG. 9 with FIG. 4) and the PSF has a functionally different form for a given value of ψ

(compare FIG. 20 with FIG. 17), in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values u and ψ, over an extended depth of focus larger than a depth of focus without the optical mask (compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

Claims 18 and 19 are for a method for imaging light from an object to form an image in an optical system (specification paragraphs **[0071]** - **[0072]** and FIG. 2). The light includes phase (as is known in the art) and which imaging system is characterized at least by an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function (PSF) (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is at least a function of the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The method comprises forming the image and detecting the image over a range of spatial frequencies (detector at specification paragraphs **[0012]**, **[0071]** and FIG. 2; range of spatial frequencies shown in FIG. 10). Forming the image includes modifying the phase without reducing the range of spatial frequencies (compare the spatial frequency range shown in FIG. 10 to that shown in FIG. 6) such that a main lobe of the ambiguity function is broader in v for a given value of u (compare FIG. 9 with FIG. 4) and the PSF has a functionally different form for a given value of ψ (compare FIG. 20 with FIG. 17), in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without modifying the phase for those given values u and ψ, over a range of object distances between the object and the imaging system (compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification

paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

Claims 20 -23 are for an imaging system characterized at least by an ambiguity function (specification paragraphs **[0074]** - **[0080]**, **[0090]** and FIG. 9) and a point spread function (PSF) (specification paragraph **[0097]** and FIG. 20 - FIG. 23). The ambiguity function is a function of a normalized spatial frequency parameter u and a misfocus parameter ψ (specification paragraphs **[0074]** - **[0076]** and FIG. 9 - FIG. 14, describing the fact that an optical transfer function ("OTF") is a radial slice of the ambiguity function wherein the slope of the slice is related to misfocus parameter ψ). The PSF is also a function of at least the misfocus parameter ψ (FIG. 21 - FIG. 23, it also being known in the art that a PSF and an OTF are Fourier Transform pairs, so the PSF is also a function of misfocus parameter ψ). The imaging system comprises a lens and an optical mask that cooperate to image light from an object to form an optical image (specification paragraphs **[0071]** - **[0072]** and FIG. 2), the light is characterized by at least phase (as is known in the art). The system also comprises a detector for detecting the optical image over a range of spatial frequencies to form a detected image (detector at specification paragraphs **[0012]**, **[0071]** and FIG. 2; range of spatial frequencies shown in FIG. 10). The optical mask is configured for modifying the phase (specification paragraphs **[0072]** - **[0073]**) such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u (compare FIG. 9 with FIG. 4) and the PSF of the system has a functionally different form (compare FIG. 20 with FIG. 17), in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ and over a range of object distances from the object to the system (compare specification paragraphs **[0088]** - **[0089]** and FIG. 7, FIG. 8 with specification paragraphs **[0092]** - **[0093]** and FIG. 12, FIG. 14 in light of the center OTF lobe corresponding to the main lobe of the ambiguity function).

(6) Grounds for rejection to be reviewed on appeal.

A) Whether the rejection of claims 7, 11-14, 16, 18, 20 and 23 is actually under 35 U.S.C. §102(b) or 35 U.S.C. §103(a).

B) Whether claims 7, 11-14, 16, 18, 20 and 23 are unpatentable under (35 U.S.C. §102(b) or) 35 U.S.C. §103(a) over Kubo.

C) Whether claims 8, 15, 17 and 21 are unpatentable under 35 U.S.C. §103(a) as obvious over Kubo in view of Poon.

D) Whether claims 19 and 22 are in fact allowable over prior art, as the Examiner has failed to so indicate.

E) Whether the Examiner's "objections" should be sustained in view of the Examiner's arguments directed to the merits of the claims, as opposed to matters of formality.

(7) Arguments.

(A) With respect to whether the rejection of claims 7, 11-14, 16, 18, 20 and 23 is actually under 35 U.S.C. §102(b) or 35 U.S.C. §103(a):

The Examiner has rejected claims 7, 11-14, 16, 18, 20 and 23 over Kubo. As noted above, the Examiner alternately characterizes this rejection first as being under 35 U.S.C. §103(a) (Office Action of 20 March 2006, paragraph 3 and the immediately preceding heading), and under 35 U.S.C. §102(b) (Office Action of 20 March 2006, paragraph 4). Appellants respectfully request that the Board clarify the Office's official position in this matter; that is, please provide an unambiguous statement as to whether the rejection of claims 7, 11-14, 16, 18, 20 and 23 is under 35 U.S.C. §102(b) or 35 U.S.C. §103(a).

(B) With respect to whether claims 7, 11-14, 16, 18, 20 and 23 are unpatentable under (35 U.S.C. §102(b) or) 35 U.S.C. §103(a) over Kubo:

As noted above, it is not clear whether the rejection of claims 7, 11-14, 16, 18 and 21 is under 35 U.S.C. §102(b) or 35 U.S.C. §103(a). However, noting that the Examiner includes statements (Office Action of 20 March 2006, page 5, last

paragraph) about what would be "obvious," Appellants provide the following remarks in the belief that the rejection of claims 7, 11-14, 16, 18, 20 and 23 is meant to be under 35 U.S.C. §103(a). The Board is respectfully requested to consider these remarks in light of their relevance under 35 U.S.C. §102(b) if it is determined that these rejections should be considered as 35 U.S.C. §102(b) rejections.

We now show that, for this rejection, the Examiner has not shown the elements of the claims to be present and disclosed in the cited reference. We will do this by (i) providing a summary of the cited reference, (ii) summarizing the Examiner's arguments, and (iii) showing why the Examiner's arguments are incorrect and the cited reference does not show the elements of the claims that the Examiner alleges. In particular, we will show that the Examiner's rejection are founded on a misinterpretation of the terminology used both in the cited reference and in the claims of the present application, as would be understood by one skilled in the art in light of the specification.

i) Summary of Kubo reference

U.S. Patent No. 4,480,896 ("Kubo") discloses an "Optical Filter Suitable for Portrait Photography." Kubo, Title. Kubo appreciates that in portrait photography, it is desirable that "the facial spots, freckles, wrinkles, and other common blemishes are reproduced softly and the other areas except for human skin are reproduced sharply..." Kubo, col. 1, lines 23-25. Therefore, "An object of the present invention is to provide an optical filter capable of producing desirable portrait photography with a sharp objective lens in such a way that a soft focus effect is produced on the color of human skin, such as a face, hands and feet, while a sharp tone effect is given to a dress, hair, etc." Kubo, col. 1, lines 29-34.

Kubo further observes:

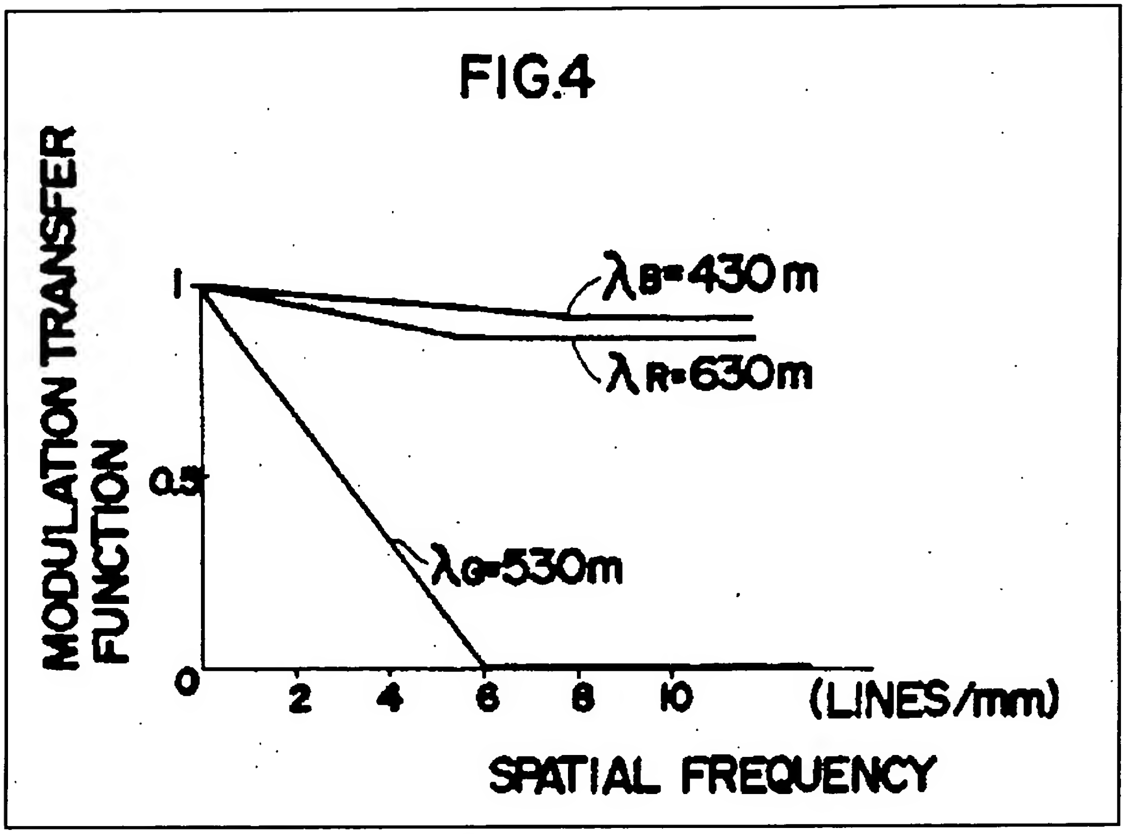
> "The human skin generally absorbs the green light because of hemoglobin in the blood, thereby causing its color to appear to be magenta. Facial spots, freckles, wrinkles, etc. are distributed on the background of the magenta color. A facial image formed by use of optical filter having a selective soft focus effect only for green light, results in the spots, freckles, etc. being imaged mainly by magenta light

> whose color is a complementary color of green, whereby the spots, freckles, etc. become inconspicuous with an approximation in magenta color to the surrounding skin." Kubo, col. 1, lines 46-50.

Kubo discloses a filter that utilizes "a plurality of transparent minute spots 11 which generate a phase difference" to reduce a modulation transfer function ["MTF"] of a photographic system in a selected wavelength band. It is known in the art that the MTF is a real magnitude of the complex OTF. Kubo presents a mathematical derivation, generally at col. 2, line 33 through col. 3, line 17, that shows how to calculate an average diameter and total area of such spots to reduce the MTF for an arbitrary light wavelength above a predetermined spatial frequency. Kubo then provides an example of tailoring such a calculation for a green light wavelength, generally at col. 3, line 18 through col. 3, line 39. Accordingly, Kubo's filter "produces desirable characteristics for portrait photography, by providing a soft focus effect for the transmitted green light and substantially no soft focus effect in the blue and red light." Kubo, col. 3, lines 42-45. Also,

> "It should be noted that the assumption of $A_{11}=A_{12}$ in the above embodiment corresponds to a case where an MTF value at the bending point (minimum MTF value) becomes zero at the design wavelength, as is apparent from formula (2)." Kubo, col. 4, lines 3-7.

Therefore, under the condition that $A_{11}=A_{12}$ (which Kubo states is not required, but is certainly possible) the MTF goes to zero above a certain spatial frequency S (S being given by formula (2) in Kubo). This is explicitly shown in FIG. 4 of Kubo:



Kubo, FIG. 4.

ii) The Examiner's arguments:

We now attempt to summarize the Examiner's key arguments here, a task that is complicated because the Examiner has delivered such arguments in a two page section that first treats claims 7, 11- 14, 16, 18, 20 and 23 as a group (see (a) below), then adds individual remarks that only cover claims 7, 11, 12, 14, 16, 18 and 20 as a group (see (b) and (c) below), further remarks that cover claims 11 and 12 as a group (see (d) below) and further remarks that cover claims 13, 16, 20 and 23 as a group (see (e) below).

The Examiner states, *inter alia*:

> (a) "Kubo et al further teaches that the optical mask also modulating [sic] the wavefront of the light from the sharp objective lens to make the imaging system has [sic] a ***soft focus effect*** which implicitly means that it creates *an extend* [sic] *of the depth of focus* that is larger than the focus of the

imaging system without the optical mask, (please see column 1-2)." Office Action of 20 March 2006, page 4.

(b) "Kubo et al does teach that the optical phase mask is capable of creating soft focus or extending the depth of the focus, it is believed that it is implicitly true that the optical mask will have this inherent function of increasing the main lobe if the optical face mask extends the depth of the focus." Office Action of 20 March 2006, page 5.

(c) "With regard to the feature concerning point spread function has a functionally different form, as recited in amended claims 7 and 11 and newly added claims 12, 14, 16 and 18-20, it is implicitly true that the point spread function for an optical imaging system with an optical phase mask and without an optical phase mask will be at least mathematically different since the point spread function for the system with the optical phase masks to include [sic] the effect of this phase mask." Office Action of 20 March 2006, page 5.

(d) "With regard to claims 11-12, the misfocus parameter stated in the claim is well known standard parameter in the art for measuring the misfocus of an imaging system. The range of the misfocus recited in claim 12 seems to be arbitrarily selected." Office Action of 20 March 2006, page 5.

(e) "With regard to claims 13, 16, 20 and 23, Kubo et al teaches that the optical phase mask is provided with an imaging system such as photographic system, which implicitly includes a lens." Office Action of 20 March 2006, page 5.

For the sake of completeness, Appellants note that not all of the Examiner's remarks are applicable to each claim in the listed group of claims. For example, claims 11 and 18 do not include a requirement of "extended depth of focus" yet are treated in the Examiner's remarks (see part (a) above, addressed to all of the rejected claims as a group). It is noted that Office Policy considers such rejections as improperly expressed: "A plurality of claims should never be grouped together in a common rejection, unless that rejection is equally applicable to all claims in the group." MPEP §707.07(d) under "Improperly Expressed Rejections."

(iii) Why the Examiner's arguments are incorrect and the cited reference does not show the elements of the claims that the Examiner alleges:

Claim 7:

The Examiner errs first by confounding the terms "soft focus effect" with "extended depth of focus," (see part (a) above) and second by making unfounded assertions about elements of claim 7 (and other claims) – based on an erroneous belief that they are "implicitly" associated with the extended depth of focus (see part (b) above).

"Soft focus effect," as used in Kubo, and "extended depth of focus" are entirely different, yet the Examiner apparently confuses them because each contains the word "focus." In layman's terms, the "soft focus effect" provided by Kubo's filter reduces the visible detail in certain colors. In optical terms, this effect is described as reducing a modulation transfer function ("MTF") of a photographic system using the filter at high spatial frequencies, but only in a specific wavelength range. MTF essentially describes how an optical system responds with respect to feature size of an object being imaged. Low spatial frequencies correspond to coarse features of the object, while high spatial frequencies correspond to fine details. Reduction of a system MTF at high spatial frequencies - such as produced by Kubo's filter, see Kubo's FIG. 4, above - corresponds to more or less normal imaging of coarse features, but with a loss of contrast in fine details, so that the details are less distinguishable. However, these effects have nothing to do with depth of focus; <u>in fact, Kubo does not say anything about depth of focus</u>.

Kubo appears to call the reduction of MTF at high spatial frequencies a "soft focus effect" because other "soft focus lenses and soft focus filters" (Kubo, col. 1, lines 15-16) may do similar things across all wavelengths. However, two very important facts distinguish the "soft focus effect" provided by Kubo's filter, from extended depth of focus:

- Kubo is quite clear (in the passages cited in subsection (i) above) that the "soft focus effect" is for, and must be limited to, the green wavelength range

for optimal portrait photography. That is, Kubo's goal is not to defeat sharp imaging entirely but to reduce only the sharpness of features imaged in a specific (green) wavelength band of imaged light. An "extended depth of focus" would apply to all wavelengths of the imaged light - yet Kubo specifically points out that the effects of the filter disclosed therein are wavelength-specific.

- Kubo does not disclose any effects of the filter disclosed therein on depth of focus, and similarly does not disclose any effects of misfocus on a system utilizing such a filter. A careful reading of Kubo reveals no disclosure at all about depth of focus or misfocus (or related terms such as object distance, depth of field, etc.). In particular, Kubo certainly does not compare depth of focus of a system utilizing such a filter to depth of focus of the system without the filter.

Given the principles on which Kubo's filter operates, it is immediately apparent to one skilled in the art that aside from the lower MTF at high spatial frequencies for a particular wavelength range, other characteristics of a system utilizing Kubo's filter - such as depth of focus - will not be changed by the presence of such a filter.

Furthermore, Kubo certainly does not disclose certain elements of claim 7, such as whether "a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values of u and ψ." The Examiner's only basis for concluding that such claim elements are present is the mistaken belief that Kubo's filter provides "extended depth of focus" (see item (a) above) and the unsupported premise "it is believed that it is implicitly true that the optical mask will have this inherent function of increasing the main lobe if the optical phase mask extends the depth of the focus" (see item (b) above).

Kubo's "soft focus effect" does <u>not</u> mean that the optical filter described therein affects depth of focus, or modifies the effects of misfocus on a system utilizing such a filter. The Examiner's argument that Kubo's "soft focus effect ... implicitly means that it creates an extend of the depth of focus" (see items (a) and (b) above) is invalid. Thus, the element of claim 7 "wherein the optical mask is configured for modifying the phase of the light such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values of u and ψ, <u>over an extended depth of focus larger than a depth of focus formed without the optical mask</u>" (emphasis added) is not taught or suggested by Kubo. Since at least this element of claim 7 is not taught or suggested by the prior art, Appellants argue that claim 7 is patentable over the prior art.

<u>Claim 11:</u>

With respect to claim 11, the Examiner points out that "the misfocus parameter ψ stated in the claim is well known standard parameter in the art for measuring the misfocus of an imaging system" (see part (d) above). We agree, but note that the Examiner has previously stated "The symbol 'ψ' recited in claim 11 is confusing and indefinite." Office Action mailed 8 July 2005, page 3. Aside from this newly acquired understanding of the terminology of the art - which does not indicate any teaching or suggestion of claim 11 by the prior art - the Examiner directs no further arguments or remarks to claim 11 than to claim 7.

Claim 11 contains the element "the optical mask modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u, and the PSF has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ." The language of claim 11 thus requires, inter alia, that a main lobe of the ambiguity function be broader for a given <u>range of ψ</u> at a given value of u in comparison to a

main lobe of an ambiguity function characterizing the imaging system without the optical mask for that given range of ψ. The requirements relating to a range of ψ are different from those articulated in claim 7, which instead has requirements relating to a depth of focus. Yet the Examiner fails to address the difference between claims 7 and 11, except through the statement pointing out a definition of ψ, not a range of ψ for which an ambiguity function must be broader at a given value of u. Kubo certainly does not explicitly disclose the element of claim 11 wherein a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u in comparison to a main lobe of an ambiguity function characterizing the imaging system without the optical mask for that given range of ψ. Since at least this element of claim 11 is not taught or suggested by the prior art, Appellants argue that claim 11 is patentable over the prior art.

Claim 12:

With respect to claim 12, the Examiner states that "The range of the misfocus recited in claim 12 seems to be arbitrarily selected" (see part (d) above). This remark appears to be irrelevant to the patentability of claim 12. We point out that Kubo does not teach or suggests an optical mask providing the effects on an ambiguity function and PSF recited in claim 11 over a misfocus range of $-\frac{\pi}{10} \le \psi \le \frac{\pi}{10}$ (because Kubo does not mention any effects related to misfocus at all), and the Examiner does not set forth any explanation as to where or how such a range is described in the prior art. Because at least this element of claim 12 is not taught or suggested by the prior art, and because claim 12 depends from claim 11, argued above as patentable, Appellants argue that claim 12 is patentable over the prior art.

Claim 13:

With respect to claim 13, the Examiner states: "With regard to claims 13, 16, 20 and 23, Kubo et al teaches that the optical phase mask is provided with an imaging system such as photographic system, [sic] which implicitly includes a lens" (see part (e) above). We point out that the Examiner's statement that a photographic system "implicitly includes a lens" is incorrect; photographic systems based on other

elements - such as mirrors or pinhole apertures - are well known. Since "a lens" is not shown, the element of claim 13 "wherein the optical mask is formed integrally with the lens" is also not shown. Because at least this element of claim 13 is not taught or suggested by the prior art, and because claim 13 depends from claim 11, argued above as patentable, Appellants argue that claim 13 is patentable over the prior art.

Claim 14:

The Examiner directs no arguments to claim 14 other than those directed to claim 7. Appellants point out that claim 14 requires "wherein imaging includes modifying the phase, such that a main lobe of the ambiguity function is broader in v for a given value of u, and the PSF has a functionally different form for a given value of ψ over an extended depth of focus that is larger than a depth of focus formed without modifying the phase, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical system without modifying the phase for those given values of u and ψ." Kubo certainly does not explicitly disclose that a main lobe of the ambiguity function is broader in v for a given value of u, and the PSF has a functionally different form for a given value of ψ over an extended depth of focus that is larger than a depth of focus formed without modifying the phase, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical system without modifying the phase for those given values of u and ψ. We reiterate the above arguments with respect to claim 7, and point out that Kubo does not extend depth of focus. Since at least this element of claim 14 is not taught or suggested by the prior art, Appellants argue that claim 14 is patentable over the prior art.

Claim 16:

The Examiner's statement about "a lens" and the above argument with respect to claim 13 is again noted. Since "a lens" is not shown, the claim 16 element "a lens and an optical mask that cooperate to image light" is also not shown.

Other than the statements about "a lens" discussed above, the Examiner directs no further arguments to claim 16 other than those directed to claims 7 and 13. However, claim 16 requires:

- a lens and an optical mask that cooperate to image light from an object to form an optical image having a range of spatial frequencies that is limited by an aperture of at least one of the lens and the optical mask, which light includes at least phase; and
- a detector for detecting the optical image over the range of spatial frequencies to generate a stored image,
- wherein the imaging system is characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ, and which PSF is at least a function the misfocus parameter ψ, and
- wherein the optical mask is configured for modifying the phase without reducing the range of spatial frequencies, such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values u and ψ, over an extended depth of focus larger than a depth of focus without the optical mask.

The first element of claim 16 requires that a lens and an optical mask cooperate to image light from an object to form an optical image having a range of spatial frequencies that is limited by <u>an aperture</u> of at least one of the lens and the optical mask. The fourth element of claim 16 requires (1) that the optical mask be configured for modifying the phase without reducing the range of spatial frequencies, (2) such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison

to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values u and ψ, over an extended depth of focus larger than a depth of focus without the optical mask.

Kubo's optical mask does not implement item (2) required by the fourth element of claim 16, and under certain conditions also does not implement item (1). Item (2) requires that the optical mask provide an extended depth of focus; as argued with respect to claim 7 above, Kubo's optical filter does not provide extended depth of focus. Item (1) requires that the optical mask not reduce the range of spatial frequencies defined in the first element of claim 16, namely, that optical image have a range of spatial frequencies that is limited by <u>an aperture</u> of at least one of the lens and the optical mask. The effect of an aperture limiting spatial frequencies of an image is well known and leads to such effects as telephoto lenses and telescopes having large apertures to achieve high resolution (that is, large lenses are required in order to have high spatial frequencies in images formed therewith). However, as noted in the above summary of the Kubo reference, Kubo's optical filter <u>does reduce high spatial frequencies</u> - for example, under the $A_{11}=A_{12}$ condition shown in FIG. 4. It follows that "without reducing the range of spatial frequencies" limited by an aperture is not an inherent or implicit feature of Kubo's optical filter, and that Kubo does not disclose this item that is required by claim 16. Since at least the "lens," the "extended depth of focus" and "without reducing the range of spatial frequencies limited by an aperture" elements of claim 16 are not taught or suggested by the prior art, Appellants argue that claim 16 is patentable over the prior art.

<u>Claim 18:</u>

The Examiner directs no arguments to claim 18 other than those directed to claim 7. Appellants point out that claim 18 requires "wherein forming the image includes modifying the phase without reducing the range of spatial frequencies, such that a main lobe of the ambiguity function is broader in v for a given value of u, and the PSF has a functionally different form for a given value of ψ in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical

system without modifying the phase for those given values of u and ψ, over a range of object distances between the object and the imaging system." Kubo certainly does not explicitly disclose that a main lobe of the ambiguity function is broader in v for a given value of u, and the PSF has a functionally different form for a given value of ψ in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical system without modifying the phase for those given values of u and ψ, over a range of object distances between the object and the imaging system. We reiterate the above arguments with respect to claim 7, and point out that Kubo does not teach or suggest these effects, or any effects that occur over a range of object distances.

We also reiterate the argument with respect to claim 16 that Kubo does not teach "modifying the phase without reducing the range of spatial frequencies." Kubo's optical filter does reduce the range of spatial frequencies under the $A_{11}=A_{12}$ condition.

Since at least the "modifying the phase without reducing the range of spatial frequencies" and "a main lobe of the ambiguity function is broader in v for a given value of u ... in comparison to a main lobe of an ambiguity function ... characterizing the optical system without modifying the phase for those given values of u and ψ, over a range of object distances between the object and the imaging system" elements of claim 18 are not taught or suggested by the prior art, Appellants argue that claim 18 is patentable over the prior art.

Claim 20:

Claim 20 contains the element "the optical mask is configured for modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u and the PSF has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ and over a range of object distances from the object to the system." The language of claim 20 thus requires, inter alia, that a main lobe of the

ambiguity function be broader for a given range of ψ at a given value of u in comparison to a main lobe of an ambiguity function characterizing the imaging system without the optical mask for that given range of ψ. As noted with respect to claim 11, the requirements relating to a range of ψ are different from those articulated in claim 7 which has requirements relating to a depth of focus. Yet the Examiner fails to address this difference between claims 7 and 20, except through the above-cited statement having to do with a definition of ψ, not a range of ψ for which an ambiguity function must be broader at a given value of u. Kubo certainly does not explicitly disclose the element of claim 20 wherein a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u in comparison to a main lobe of an ambiguity function characterizing the imaging system without the optical mask for that given range of ψ.

Since at least the "a lens" and the "main lobe of the ambiguity function be broader for a given range of ψ at a given value of u in comparison to a main lobe of an ambiguity function characterizing the imaging system without the optical mask for that given range of ψ" requirements of claim 20 are not taught or suggested by the prior art, Appellants argue that claim 20 is patentable over the prior art.

Claim 23:

The Examiner's statement about "a lens" and the above argument with respect to claims 13, 16 and 20 is again noted (see part (e) above). Since "a lens" is not shown, the element of claim 23 "wherein the optical mask is formed integrally with the lens" is also not shown. Because "the optical mask is formed integrally with the lens" is not shown, and because claim 23 depends from claim 20, argued above as patentable, Appellants argue that claim 23 is patentable over the prior art.

(C) With respect to whether claims 8, 15, 17 and 21 are unpatentable under 35 U.S.C. §103(a) as obvious over Kubo in view of Poon:

The Examiner has rejected claims 8, 15, 17 and 21 under 35 U.S.C. §103(a) as unpatentable over Kubo in view of the article "Optical/Digital incoherent image

processing for extended depth of field" by Poon et al. in Applied Optics, vol. 26, no. 21, page 4612, November 1987 ("Poon").

We will show, for this rejection, that the Examiner has not shown all of the elements of the claims to be present in the cited references, that the system proposed by the Examiner cannot work, and that, in fact, both of the cited references teach away from the proposed combination. We will do this by (i) providing a summary of the Poon reference (the Kubo reference being summarized in part (B) above), (ii) summarizing the Examiner's arguments, and (iii) showing why the Examiner's arguments are incorrect, that the cited reference does not show the elements of the claims that the Examiner alleges, that the system proposed by the Examiner cannot work, and that both of the cited references teach away from the proposed combination.

i) Summary of Poon reference

The Poon article discloses "Optical/digital incoherent image processing for extended depth of field." Poon, Title, page 4612. Poon appreciates that zeros in an optical transfer function of a system - which are appreciated by those skilled in the art as a lack of information at spatial frequencies corresponding to the zeros - preclude exact inverse filtering by any means. But Poon also appreciates that an <u>annular aperture</u> with a properly chosen radius ratio does not introduce zeros into the OTF, and that <u>annular-pass filtering</u> can be utilized to restore image contrast lost <u>by use of the annular aperture</u>:

> "For a severely defocused incoherent system, its optical transfer function (OTF) has isolated zeros; therefore, an exact inverse filtering cannot be performed. Isolated zeros in the OTF can be avoided by choosing an annular aperture with a proper radius ratio, as the aperture can extend the depth of focus of the system. However, in the process of increasing the depth of focus of the system, this method results in a loss of image contrast. ... Annular-pass filtering to compensate for the loss of contrast is performed by a digital computer." Poon, Abstract.

Poon discloses, by way of introduction, a number of approaches for increasing depth of field. Poon, "Introduction," page 4612. Poon derives expressions for depth

of focus as a function of annular aperture parameters. Poon, "A. Depth of Focus," pages 4612-4613. Poon discusses effects of the <u>annular aperture</u> on optical transfer function. Poon, "B. Optical transfer function," pages 4613-4614. In particular, Poon teaches how certain aspects of an optical transfer function are set by parameters such as an obscuration ratio $\epsilon = b/a$ (where b is the diameter of a central obscuration of an annular aperture, and a is the outer diameter of the aperture), the well known F number of the optical system, expressed as $f/2a$, and a wavelength λ of light being imaged. Poon shows these aspects of the OTF in Fig. 3(a) and Fig. 3(b): "The approximate cross section along f_x of the OTF is sketched in Fig. 3(s), and the normalized OTF is illustrated in Fig. 3(b)." Poon, p. 4613. Fig. 3(b) of Poon is shown below. It is understood by those skilled in the art that an OTF is a complex variable, and that calculations of an OTF may be carried out in complex form; but when shown graphically, what is shown is the real magnitude of the OTF. This real magnitude is also known as the modulation transfer function or MTF (discussed above with respect to the Kubo reference).

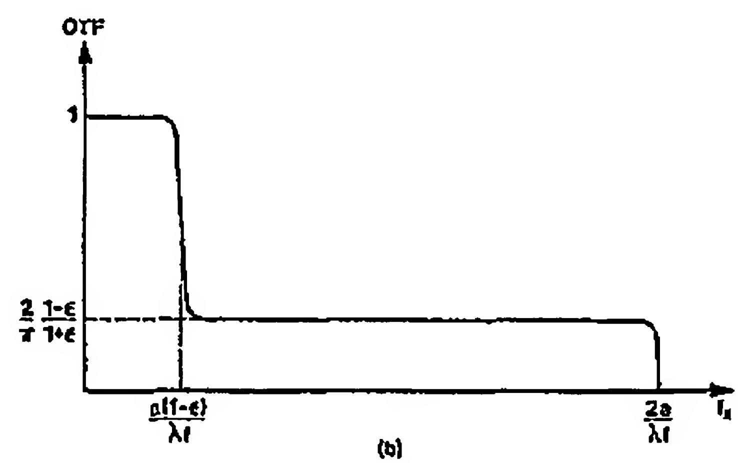


Fig. 3. (a) OTF of system with annular aperture; (b) normalized OTF.

Poon, Fig. 3(b)

Inspection of Fig. 3(b) of Poon shows that the OTF drops from its normalized level of 1, at low spatial frequencies, to a level that depends on the obscuration ratio ϵ, over a spatial frequency range that depends on ϵ, a, f and λ. Significantly, Poon does not teach or suggest the effects on OTF of any filters other than an annular aperture.

Next, Poon discusses inverse filtering, but again, only in the context of filtering images created utilizing the annular aperture:

> "Now suppose we have an object of which the spectrum F_dF_i represents a picture taken with a lens and an annular aperture, where F_i denotes the ideal image without degradation and F_d a filter function which expresses the degradation and is shown in Fig. 3(b). We can restore F_i by using a filter with the transfer characteristic F_d^{-1}. In this specific case, F_d^{-1} must have the characteristics as shown in Fig. 4. In two dimensions, this is an annular-pass filter." Poon, "C. Inverse Filtering," page 4614.

Fig. 4 of Poon is shown below:

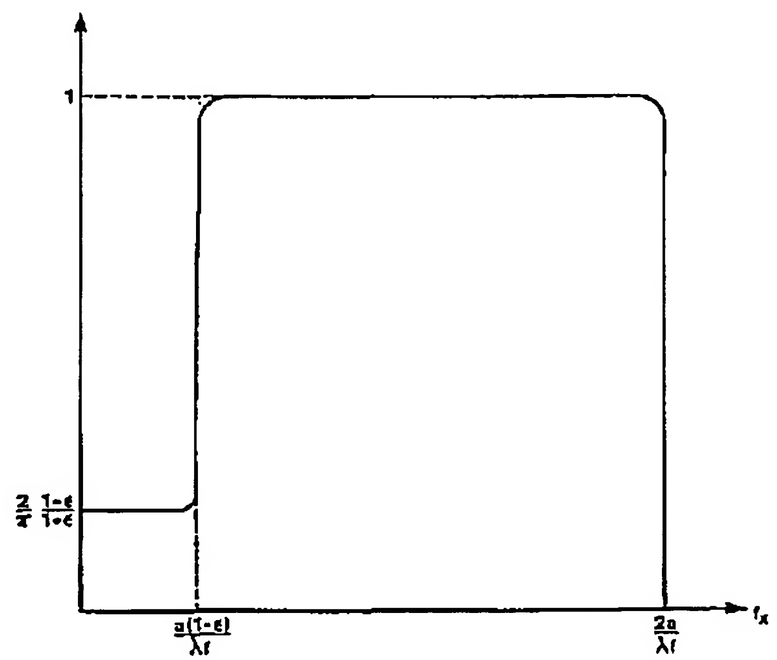


Fig. 4. Annular-pass filter.

Poon, Fig. 4.

Poon's Fig. 4 shows that the inverse filter proposed for application to the OTF shown in Fig. 3(b) inverts the effects of the OTF at each spatial frequency as determined by annular aperture parameters. That is, it reduces response for the low spatial frequencies where OTF was not reduced by the annular aperture, and it does not reduce response at those spatial frequencies where OTF was reduced by the annular aperture. The magnitude of the reduction for low spatial frequencies by the inverse filter is the same as the magnitude of the reduction of the OTF for higher spatial frequencies. All of the spatial frequencies and levels of the OTF and of the inverse filter are set by parameters of the annular aperture system.

Poon goes on to demonstrate the results of the described system and makes concluding remarks. Poon, "III. Hybrid Processing System and Experimental Results" and "IV. Concluding Remarks," pages 4614-4615.

ii) The Examiner's arguments:

The Examiner states, *inter alia*:

> (a) "The optical mask taught by **Kubo** et al that modulates phase of the wavefront and creates soft focus effect for an optical imaging system including [sic] a sharp focus objective lens as described for claim 7 above has met all the limitations of the claims. It is implicitly true that an imaging system has a detector for detecting the optical image however this reference does not teach explicitly to include a post-processor for processing the detected optical image to reverse the blurring effect." Office Action of 20 March 2006, page 6.
>
> (b) "Poon et al further teaches to include *digital image* processing arrangement, serves as the post processor, (please see Figure 5), including a *computer generated filter* to *reverse* or *compensating* [sic] the effects of the mask so that the lost image contrast in the detected image can be restored. … It would then have been obvious to one skilled in the art to apply the teachings of Poon et al to apply this post-processing scheme to the detected image and to add this digital image process arrangement to the imaging system of Kubo et al for the benefit of allowing the blurring effect introduced by the optical mask be reversed or eliminated so that a clearer image can be obtained in the photographic imaging system." Office Action of 20 March 2006, pages 6 - 7, emphasis in original.

We note that in (a) above, the Examiner states "The optical mask taught by **Kubo** et al … has met all the limitations of the claims. … however this reference

does not teach explicitly to include a post-processor for processing the detected optical image to reverse the blurring effect." Upon reading this passage, it appears that the Examiner first says that Kubo meets all of the limitations of claims 8, 15, 17 and 21, but then says that Kubo does not. In light of these contradictory statements, we suggest that the Examiner meant to allege that Kubo meets the limitations of claim 7, but does not include the post-processor limitations of claims 8, 15, 17 and 21. These contradictory statements and Appellants' interpretation of the Examiner's intent were pointed out in the response filed 19 May 2006; the Examiner has remained silent on this issue, so we continue based on this interpretation.

The Examiner's statements appear to reduce to an argument that applying the post-processor of Poon to a photographic system that utilizes Kubo's "optical mask" shows the elements of Appellants' claims 8, 15, 17 and 21. We note that no remarks or arguments in the Examiner's rejection of claims 8, 15, 17 and 21 differentiate among these claims.

(iii) Why the Examiner's arguments are incorrect and the cited reference does not show the elements of the claims that the Examiner alleges:

<u>Claim 8:</u>

Claim 8 is for "The system of claim 7, further comprising a post-processor for processing the stored image, in accordance with the PSF, to remove imaging effects induced by the optical mask and to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the system and without the optical mask and over the extended depth of focus."

We point out first, that claim 8 depends from claim 7 and benefits from like arguments for patentability.

Second, claim 8 requires a post processor "for processing the stored image,

(a) <u>in accordance with the PSF</u>, to

(b) <u>remove imaging effects induced by the optical mask</u> and to form an electronic image that is

(c) <u>clearer... over the extended depth of focus.</u>"

We will show that Poon's post-processor does not - and, in fact, can not - show these elements of claim 8, as the Examiner asserts.

With respect to element (a), the Examiner has not established that the post processor of Poon can perform processing "in accordance with the PSF" when Kubo's optical filter is utilized as the mask. Poon discloses only processing in accordance with effects of an annular aperture. Such processing may be appropriate for an image obtained with an annular aperture, but not for an image obtained with Kubo's optical filter. (In fact, Poon's annular aperture is not even "configured to modify phase" as required by claim 7, from which claim 8 depends. An annular aperture is an amplitude mask - and the Examiner has not shown how Poon's post processing could be appropriate for any phase mask, let alone the specific phase mask shown in Kubo.)

Poon clearly shows how the post-processing is tailored to the OTF of the annular aperture - an OTF that is not replicated by Kubo's optical filter. Compare FIG. 4 of Kubo, shown above in connection with claim 7, with Fig. 3(b) of Poon in the immediately preceding section. The OTF (MTF) of Poon is not the same as the MTF produced by Kubo's optical filter. Poon's annular aperture reduces the MTF to a constant level within a spatial frequency range, while Kubo's optical filter reduces the MTF linearly with respect to spatial frequency, until the MTF reaches zero (at least for green wavelengths). Recall, from "Summary of the Claimed Subject Matter" section that it is known that a PSF and an OTF are Fourier Transform pairs, therefore processing "in accordance with the PSF" as required by claim 8 relates such processing to the MTF; if two systems produce differing MTFs they will also have differing PSFs. The Examiner does not show - or even attempt to explain - how Poon's post processor can process or be modified to process "in accordance with the PSF" produced by Kubo's optical filter; therefore element (a) of claim 8 is not shown by Kubo in view of Poon.

With respect to element (b) of claim 8, Poon's post processor - or any post processor - cannot "remove imaging effects induced by the optical mask" - at least at

green wavelengths - because the information required to remove the imaging effect is simply missing! Note in Kubo's FIG. 4 how the MTF is reduced to zero for green wavelengths. It is understood in the art of imaging that information that is lost optically cannot be restored. Some information - that is, an MTF that is not zero - is at least required. Note in Poon's Fig. 3(b) that the MTF is not reduced to zero at higher spatial frequencies - it is merely reduced. Since Kubo's MTF is reduced to zero for green wavelengths, Poon's post processor cannot "remove imaging effects induced by the optical mask"; therefore element (b) of claim 8 is not shown by Kubo in view of Poon.

With respect to element (c) of claim 8, even if Poon's post processor could process in accordance with elements (a) and (b) of claim 8 - which we have shown that it cannot do - it could still not form an electronic image that is clearer... over the extended depth of focus" because, as shown in connection with claim 7 above, Kubo's optical filter does not extend depth of focus. We refer to the arguments regarding claim 7 pointing out that Kubo does not disclose any effects of the filter disclosed therein on depth of focus, and similarly does not disclose any effects of misfocus on a system utilizing such a filter. Therefore element (c) of claim 8 is not shown by Kubo in view of Poon.

Furthermore, both Kubo and Poon teach away from the combination proposed by the Examiner.

As noted in (B)(i) above, Kubo states "A facial image formed by use of optical filter having a selective soft focus effect only for green light, results in the spots, freckles, etc. being imaged mainly by magenta light whose color is a complementary color of green, whereby the spots, freckles, etc. become inconspicuous with an approximation in magenta color to the surrounding skin." Kubo, col. 1, lines 46-50. Thus, Kubo intends that high spatial frequency information in green wavelengths should be eliminated, to render features that are imaged in magenta light inconspicuous – so it follows that such information should not be reintroduced into an image by post processing. Poon's post processing – even if it

were possible, as per arguments above – would defeat this explicit aim of Kubo's optical filter.

Poon is quite clear that an optical system must not introduce zeros into an OTF, because such zeros represent permanently lost information that cannot be restored by post processing (see "Summary of Poon reference" under (C)(i) above). Yet, Kubo's optical filter is set up to explicitly introduce zeros into an MTF of an optical system, under the $A_{11}=A_{12}$ condition and for green wavelengths. Kubo's optical filter thus does exactly what Poon teaches an optical filter should not do.

Since at least the elements (a), (b) and (c) of claim 8 as listed above are not taught or suggested by the prior art, since the modification proposed by the Examiner would not work, and since both the Kubo and Poon references teach away from the proposed combination of Kubo and Poon, Appellants argue that claim 8 is patentable over the prior art.

Claim 15:

The Examiner directs no arguments to claim 15 other than those directed to claim 8.

We point out first, that claim 15 depends from claim 14 and benefits from like arguments for patentability.

Second, claim 15 requires "post-processing the stored image to remove imaging effects induced in the image by modifying the phase, to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the imaging system without modifying the phase." We point out, as discussed in detail with respect to claim 8 above, that (1) Poon does not teach or suggest post-processing to "remove imaging effects" produced by an optical filter such as Kubo's; (2) Poon's post processing methods do not and cannot "remove imaging effects" when information required to remove the imaging effects is missing, such as in images obtained with Kubo's optical filter; (3) that Kubo's optical filter does not produce "extended depth of focus"; and (4) that both the Kubo and Poon references teach away from the proposed combination.

Since the "remove imaging effects" and "clearer over the extended depth of focus" elements of claim 15 are not shown, since both the Kubo and Poon references teach away from the proposed combination of Kubo and Poon, and since claim 15 depends from claim 14, argued above as patentable, Appellants argue that claim 15 is patentable over the prior art.

Claim 17:

The Examiner directs no arguments to claim 17 other than those directed to claim 8.

We point out first, that claim 17 depends from claim 16 and benefits from like arguments for patentability.

Second, claim 17 is for "The system of claim 16, further comprising a post-processing arrangement for processing the stored image to remove imaging effects induced by the optical mask, to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the system without the optical mask and over the extended depth of focus." We point out, as discussed in detail with respect to claims 8 and 15 above, that (1) Poon does not teach or suggest post-processing to "remove imaging effects" produced by an optical filter such as Kubo's; (2) Poon's post processing methods do not and cannot "remove imaging effects" when information required to remove the imaging effects is missing, such as in images obtained with Kubo's optical filter; (3) that Kubo's optical filter does not produce "extended depth of focus"; and (4) that both the Kubo and Poon references teach away from the proposed combination.

Since the "remove imaging effects" and "clearer over the extended depth of focus" elements of claim 17 are not shown, since both the Kubo and Poon references teach away from the proposed combination of Kubo and Poon, and since claim 17 depends from claim 16, argued above as patentable, Appellants argue that claim 17 is patentable over the prior art.

Claim 21:

The Examiner directs no arguments to claim 21 other than those directed to claim 8.

We point out first, that claim 21 depends from claim 20 and benefits from like arguments for patentability.

Second, claim 21 is for "The system of claim 20, further comprising a post-processor for processing the detected image, to remove imaging effects induced in the optical image by the optical mask and to form an electronic image that is clearer, as compared to an electronic image that would be formed by the system without the optical mask, over the range of object distances." We point out, as discussed in detail with respect to claims 8, 15 and 17 above, that (1) Poon does not teach or suggest post-processing to "remove imaging effects" produced by an optical filter such as Kubo's; (2) Poon's post processing methods do not and cannot "remove imaging effects" when information required to remove the imaging effects is missing, such as in images obtained with Kubo's optical filter; and (3) that both the Kubo and Poon references teach away from the proposed combination.

Since the "remove imaging effects" element of claim 21 is not shown, since both the Kubo and Poon references teach away from the proposed combination of Kubo and Poon, and since claim 21 depends from claim 20, argued above as patentable, Appellants argue that claim 21 is patentable over the prior art.

(D) With respect to whether claims 19 and 22 are in fact allowable over prior art, as the Examiner has failed to so indicate:

Appellants note that neither of sections 4 and 5 of the Office Action of 20 March 2006 lists any rejection of claim 19 or claim 22.

As noted above under item (B), the Examiner directs comments to "claims 18-20," seemingly including claim 19, but each of these statements appears only to list features included in certain claims: "The amended claims 7 and 11 and the newly submitted claims 12, 14, 16, and 18-20 have added the following features…" Office Action of 20 March 2006, page 4. "…recited in amended claims 7 and 11 and newly

added claims 12, 14, 16, and 18-20..." Office Action of 20 March 2006, page 5 (two instances).

We note that it is common Office practice to point out when subject matter is found to be allowable over prior art of record, but that the Examiner has not done so in this case. In fact, we have pointed out in a previous response that claims 19 and 20 were not rejected in the Office Action of 20 March 2006, yet the Examiner has not responded to this statement: "We gratefully acknowledge that the Examiner has not rejected claims 19 or 22 under 35 U.S.C. §103(a) or 35 U.S.C. §102(b))." Appellants' Response to Office Action sent via facsimile on 19 May 2006, page 13.

Appellants therefore believe claims 19 and 22 to be allowable over the prior art of record in this case, and request an affirmative indication thereof by the Board, so that it will be understood that these claims will be allowed if issues such as informalities and double patenting rejections are attended to.

(E) With respect to whether the Examiner's "objections" should be sustained in view of the Examiner's arguments directed to the merits of the claims, as opposed to matters of formality:

Appellants are aware that "objections," per se, are not appealable to the Board of Patent Appeals and Interferences. However, the Examiner's improper application of "objections" to claims 7, 8 and 11-23 renders them appealable because the Examiner supports the "objections" with arguments directed to the merits of the claims. This position is supported by the MPEP: "The practical difference between a rejection and an objection is that a rejection, involving the merits of the claim, is subject to review by the Board of Patent Appeals and Interferences..." MPEP §706.01, emphasis added.

The Examiner makes many statements that indicate confusion about the terminology utilized in the claims, and/or an opinion that the terminology is indefinite:

> "...firstly it is really not clear what exactly is the physical meaning of this ambiguity function and it is really not clear what is the physical

> meaning of this vertical variable' to make the ambiguity function not being [sic] ambiguous and has [sic] definite physical meaning... claims further recite the phrase 'such that a main lobe of the ambiguity function is broader in v for a given value of u' that is really confusing since both the ambiguity function and the variable v are not defined in the [sic] physical terms it is is not clear what exactly is the physical meaning of this phrase... What is considered to be 'vertical variable' ? Vertical respect to what? [sic] ... the phrase 'the PSF has a functionally different form' is confusing and indefinite... **For the above reasons the scopes of the claims are not well definite**.[sic] Appropriate correction is required." Office Action of 20 March 2006, pages 2-3, emphasis in original.

The Examiner's remark in a subsequent Advisory Action also addresses claim terminology issues raised in the "objections," but refers to them as if they had been contained in "rejections" :

> "Continuation of 11. does NOT place the application in condition for allowance because: applicant'sa rguments [sic] are not persuasive to overcome the rejections. The applicant is respectfully noted [sic] that the arguments provided in the Remark is not part of the original disclosure of the specificaiton [sic] of the application. The arguments provided in the remark can provide useful information for the arguments but the terminology and the meanings of the phrases used in the claims have to be founded in the specificaiton [sic]. The claims contain a lot of variables without physical meanings to logically define the claims. Phrases such as 'functional form' could be anything. Ambiguity function in the claims is just a function but has no physcial [sic] meaning. Without definitely define [sic] the claims, it is impossible to determine the allowable subject matters. Applicant needed to address the rejections concerning the double patenting rejections of the claims." Advisory Action mailed on 9 June 2006, continuation sheet.

We have previously pointed out that "issues of language that are alleged to affect definiteness of a claim are not 'informalities' or 'formal matters' as the term is generally understood." Response to Office Action sent by facsimile on 19 May 2006, page 3. Furthermore, the MPEP explicitly clarifies that matters touching the merits of the claims are to be met with "rejections" :

> "Where a claim is refused for any reason relating to the merits thereof it should be 'rejected' and the ground of rejection fully and clearly stated, and the word 'reject' must be used. The examiner should designate the *statutory basis* for any ground of rejection by express reference to a section of 35 U.S.C. in the opening sentence of each

> ground of rejection. If the claim is rejected as broader than the enabling disclosure, the reason for so holding should be given; if rejected as indefinite the examiner should point out wherein the indefiniteness resides; or if rejected as incomplete, the element or elements lacking should be specified, or the applicant be otherwise advised as to what the claim requires to render it complete." MPEP §707.07(d).

Therefore, we contend that the Examiner's "objections" are improper insofar as they appear to relate to the merits of the claims, and that the Examiner's arguments directed towards the merits of the claims in support of the "objections" <u>make the "objections" appealable</u>. MPEP §706.01, *supra*.

We request, first, that the Board declare the "objections" moot since they are improperly based and expressed: "The examiner should designate the *statutory basis* for any ground of rejection by express reference to a section of 35 U.S.C. in the opening sentence of each ground of rejection." Id. The Examiner has not identified a statutory basis for the "objections."

However, we are compelled to respond as though the "objections" were "rejections" and answer the substance thereof - even though we are at a loss to know with certainty what statutory basis is invoked for such rejections, as required by Office policy.

Further complicating this response, the Examiner applies the "objections" to all of the claims - even though not all of the claims thus "objected to" contain the same language - and appends a list of several questions to each of the "objections." We are compelled to respond to each "objection" and each question appended thereto for the sake of completeness.

(i). The Examiner states: "The **amended** claims and the newly added claims recite a phrase 'an ambiguity function ... is a function of normalized spatial frequency parameter u and a vertical variable v related to misfocus parameter ψ' that is confusing and indefinite since firstly it is really not clear what exactly is the physical meaning of this ambiguity function and it is really not clear what is the physical meaning of this vertical variable' to make the ambiguity function not being [sic] ambiguous and has [sic] definite physical meaning. ... What is considered to be

'vertical variable' ? Vertical respect to what? [sic]" Office Action of 20 March 2006, page *2*, emphasis in original.

We point out, first, that the Examiner does not mention by claim number which claims this objection applies to; we therefore assume that it refers only to the claims that contain all of the language quoted by the Examiner. (We note that, again, the Examiner's "objections" are not in accordance with Office policy that requires clarity: "A plurality of claims should never be grouped together in a common rejection, unless that rejection is equally applicable to all claims in the group." MPEP §707.07(d).) These are claims 7, 14, 16 and 18 (other independent claims 11 and 20 include reference to an ambiguity function but not vertical variable v).

Second, no provision of Office policy or law requires that every term in a claim have a "physical" meaning. We are aware of, and believe that we have complied with, all requirements such as those under 35 U.S.C. §112, first paragraph, insofar as all of the terms in the claims have <u>definite</u> meaning.

Third, we point out that ample clarification and reference <u>to the specification</u> has been provided in the Response filed by facsimile on 19 May 2006 and in previous responses.

To address the substance of the Examiner's remarks in both the Office Action mailed 20 March 2006 and the Advisory Action, <u>the specification</u> of the present application contains ample clarification and definition of the terms questioned by the Examiner. An ambiguity function has physical meaning in that it represents - that is, it may be used to determine - optical transfer functions:

> "It can be shown that the OTF and the ambiguity function are related as:
>
> $$H(u, \psi) = A(u, u\psi/\pi)$$
>
> "Therefore, the OTF is given by a radial slice through the ambiguity function A(u,v) that pertains to the optical mask function $\hat{P}(x)$. This radial line has a slope of ψ / π. The process of finding the OTF from the ambiguity function is shown in FIGS. 4-8. The power and utility of the relationship between the OTF and the ambiguity function lie in the fact that a single two dimensional function, A(u,v), which depends uniquely on the optical mask function $\hat{P}(x)$, can represent the OTF for all values of misfocus. Without this

> tool, it would be necessary to calculate a different OTF function for each value of misfocus, making it difficult to determine whether the OTF is essentially constant over a range of object distances." Specification as filed, paragraph **[0076]**.

Other materials have also been provided to the Examiner to assist in explaining the terminology of the claims. A Rule 132 Declaration (the "Declaration") was filed on 5 May 2005. Also, in an Interview held on 6 December 2005, it was agreed that the officially-filed Response to the Office Action mailed 8 July 2005 would include a tutorial of Wavefront Coding technology. A "Tutorial of Wavefront Coding" (the "Tutorial") of some 22 pages, conforming to this agreement, was supplied in the Amendment mailed on 6 January 2006. Both of these documents are appended hereto in the Evidence Appendix. The Tutorial and the Declaration provide further guidance for the meanings of these terms. For example, and as noted in previous responses, see paragraph (8) of the Declaration, and pages 15, 16, 19, 20, 21, 23, 30, 31 and 32 of the Tutorial (referring to the page numbers of the Amendment that contains the Tutorial), all which of which include information related to the ambiguity function and/or the v-axis related to vertical variable v.

A relationship between an ambiguity function and optical transfer functions is also well established in the optical literature. The ambiguity function of an optical system is a polar display of the optical transfer function with the misfocus parameter ψ as variable.

With respect to the "meaning" of v, Appellants point out that such meaning is implicit in the above-quoted passage of the specification. Since $H(u, \psi) = A(u, u\psi/\pi)$, and the OTF - that is, $H(u, \psi)$ - is given by a radial line through $A(u,v)$ with a slope of ψ / π, it follows directly that $v = u\psi/\pi$. v is therefore a product of spatial frequency u and misfocus ψ, scaled by a factor of π. This is not necessarily a "physical" meaning, but it is a functional meaning - and as noted above, no provision of Office policy or of law requires a "physical" meaning of claim terms.

Based on this information, we disagree with the Examiner's assertion that the terms mentioned are "confusing" or that they render any of the claims indefinite. We

contend that as used in each of claims 7, 14, 16 and 18, the terms "ambiguity function" and "vertical variable *v*" have definite meanings and certainly do not raise any issues of "formality" as would be necessary to result in an "objection" to the claims. We request withdrawal of this "objection" to claims 7, 14, 16 and 18. We also request withdrawal of this "objection" to claims 11 and 20 for like reasons, although claims 11 and 20 contain only some of the language "objected to."

(ii). The Examiner states: "The amended claims and the newly added claims further recite the phrase 'such that a main lobe of the ambiguity function is broader in *v* for a given value of u' that is really confusing since both the ambiguity function and the variable *v* are not defined in the physical terms [sic] it is not clear what exactly is the physical meaning of this phrase. Also what does it mean that the 'main lobe' is broader? What is being measured by this 'lobe' or 'main lobe' to make the phrase with [sic] definite physical meaning?" Office Action of 20 March 2006, page 2. The ambiguity function and vertical variable v having been dealt with in section (i) above, we will now discuss the meaning of "main lobe."

We point out, first, that the Examiner does not mention by claim number which claims this objection applies to; we assume that it refers only to the claims that contain all of the language quoted by the Examiner. These are claims 7, 11, 14, 16, 18 and 20.

Second, we point out that ample clarification and reference to the specification has been provided in the Response filed by facsimile on 19 May 2006 and in previous responses. The <u>specification</u> discusses a main lobe of an ambiguity function at paragraphs **[0102]** and **[0113]**. Furthermore, pages 19, 30, 31 and 32 of the Tutorial all include information related to the "main lobe."

Based on this information, we disagree with the Examiner's assertion that the term "main lobe" is "confusing" or that it renders any of the claims indefinite. We contend that as used in each of claims 7, 11, 14, 16, 18 and 20, the term "main lobe" has definite meaning and certainly does not raise any issues of "formality" as would

be necessary to result in an "objection" to the claims. We request withdrawal of this "objection" to claims 7, 11, 14, 16, 18 and 20.

(iii). The Examiner states: "The amended claims and the newly added claims recite the phrase 'the PSF has a functionally different form' is confusing and indefinite since it is not clear what does it mean by 'functionally different form'? Does it mean different mathematical function form? Or does it mean it has different optical or physical functions?" Office Action of 20 March 2006, pages 2-3.

We point out, first, that the Examiner does not mention by claim number which claims this objection applies to; we assume that it refers only to the claims that contain all of the language quoted by the Examiner. These are claims 7, 11, 14, 16, 18 and 20.

Second, we point out that ample clarification and reference to the specification has been provided in the Response filed by facsimile on 19 May 2006 and in previous responses. The specification discusses appearance differences between PSFs of a prior art imaging system and an embodiment, at paragraph **[0097]**. FIG. 17 shows a PSF of a prior art imaging system, for a given value of ψ; in this case, $\psi = 0$. FIG. 20 shows a PSF according to one embodiment, that has a functionally different form for a given value of ψ; in this case, $\psi = 0$. The specification states: "Figure 20 shows the PSF for the Figure 2 C-PM system with no misfocus, before filtering (post-processing). It does not look at all like the ideal PSF of Figure 17..." Specification as filed, page 23, lines 13-16. The difference in appearance between the PSFs shown in FIG. 17 and FIG. 20 represents a difference in functional form.

Furthermore, pages 17, 21, 22, 24, 25 and 33 of the Tutorial all include information related to the "functional form of the PSF."

Based on this information, we disagree with the Examiner's assertion that the term "the PSF has a functionally different form" is "confusing" or that it renders any of the claims indefinite. We contend that as used in each of claims 7, 11, 14, 16, 18 and 20, the term "the PSF has a functionally different form" has definite meaning and certainly does not raise any issues of "formality" as would be necessary to result in an

"objection" to the claims. We request withdrawal of this "objection" to claims 7, 11, 14, 16, 18 and 20.

(iv). The Examiner directs no arguments or remarks towards any of claims 8, 12, 13, 15, 17, 19 and 21-23. Absent a showing of why these claims are "objected to" we request withdrawal of the "objection" to these claims.

(8) Claims Appendix.

Appellants provide a copy of the claims involved in this appeal as an appendix hereto.

(9) Evidence Appendix.

Appellants provide copies of the following evidence, which was entered by the Examiner, as an appendix hereto. The numbers below correspond to tabs placed on the first page of each item.

1. Declaration of Wade Thomas Cathey, submitted under 37 CFR §1.132 on 9 May 2005, three pages.

2. Tutorial of Wavefront Coding, as requested by the Examiner and supplied by Appellants in the Amendment and Response submitted 9 January 2006. (Note, as the pages submitted herewith are true copies, a passage of the Amendment and Response that does not form part of the Tutorial remains on the leading page.)

(10) Related Proceedings Appendix.

To Appellants' knowledge, there are no decisions rendered by a court or the Board for submission with this appeal.

Conclusion

Appellants respectfully submit that the Examiner's rejections under 35 U.S.C. §102(b) and/or 35 U.S.C. §103(a) of claims 7, 8, 11-18, 20, 21 and 23 over Kubo and/or Poon are not supportable. We point out that claims 19 and 22 are apparently not rejected over prior art, yet the Examiner has not acknowledged this; we request an affirmative statement by the Board regarding the patentability of claims 19 and 22 over prior art. We submit that the Examiner has improperly raised "objections" based on the merits of the claims rather than on matters of form; that the "objections" are applied indiscriminately to all of the claims; that the "objections" to claims 7, 11, 14, 16, 18 and 20 are without merit, and that no showing of reasons has been made for "objections" to claims 8, 12, 13, 15, 17, 19 and 21-23.

Other than the costs for this appeal brief and a three-month extension of time, we believe no additional fees are due in connection with this matter. However, if any additional fee is deemed necessary, the Commissioner is hereby authorized to charge such fee to Deposit Account No. 12-0600.

Respectfully submitted,

By: John Lindemann

John Lindemann, Reg. No. 54,273
LATHROP & GAGE L.C.
4845 Pearl East Circle, Suite 300
Boulder, CO 80301
Telephone: (720) 931-3018
Facsimile: (720) 931-3001

CLAIM APPENDIX TO APPEAL BRIEF

1-6. (Cancelled).

7. (Previously Presented) An imaging system characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ, and which PSF is at least a function of the misfocus parameter ψ, the imaging system comprising:

at least one lens and an optical mask that cooperate to image light from an object to form an optical image, which light is characterized by at least phase; and

a detector for detecting the optical image over a range of spatial frequencies to generate a stored image,

wherein the optical mask is configured for modifying the phase of the light such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values of u and ψ, over an extended depth of focus larger than a depth of focus formed without the optical mask.

8. (Previously Presented) The system of claim 7, further comprising a post-processor for processing the stored image, in accordance with the PSF, to remove imaging effects induced by the optical mask and to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the system and without the optical mask and over the extended depth of focus.

9-10. (Cancelled).

11. (Previously Presented) An imaging system having insensitivity to misfocus, the imaging system being characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a misfocus parameter ψ, and which PSF is also a function of at least the misfocus parameter ψ, the imaging system comprising:

at least one lens, an optical mask and a detector that cooperate to image light from an object to form a stored image, which lens is characterized by at least a length L, a focal length f, a front principal plane and a rear principal plane, and which light is characterized by at least phase and a wavelength λ, the optical mask modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u, and the PSF has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ, defined by the equation:

$$\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right),$$

where d_o is a distance from the object to the front principal plane and d_i is a distance from the rear principal plane to the detector.

12. (Previously Presented) The imaging system of claim 11, wherein the range of the misfocus parameter is a range defined as $-\frac{\pi}{10} \leq \psi \leq \frac{\pi}{10}$.

13. (Previously Presented) The imaging system of claim 11, wherein the optical mask is formed integrally with the lens.

14. (Previously Presented) A method for imaging, in an optical system characterized by at least an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a

vertical variable v related to a misfocus parameter ψ, and which PSF is at least a function of the misfocus parameter ψ, the method comprising:

imaging light from an object to form an optical image, which light is characterized by at least phase; and

detecting the optical image to generate a stored image,

wherein imaging includes modifying the phase, such that a main lobe of the ambiguity function is broader in v for a given value of u, and the PSF has a functionally different form for a given value of ψ over an extended depth of focus that is larger than a depth of focus formed without modifying the phase, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the optical system without modifying the phase for those given values of u and ψ.

15. (Previously Presented) The method of claim 14, further comprising:

post-processing the stored image to remove imaging effects induced in the image by modifying the phase, to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the imaging system without modifying the phase.

16. (Previously Presented) An imaging system, comprising:

a lens and an optical mask that cooperate to image light from an object to form an optical image having a range of spatial frequencies that is limited by an aperture of at least one of the lens and the optical mask, which light includes at least phase; and

a detector for detecting the optical image over the range of spatial frequencies to generate a stored image,

wherein the imaging system is characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ, and which PSF is at least a function the misfocus parameter ψ, and

wherein the optical mask is configured for modifying the phase without reducing the range of spatial frequencies, such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for those given values u and ψ, over an extended depth of focus larger than a depth of focus without the optical mask.

17. (Previously Presented) The imaging system of claim 16, further comprising

a post-processing arrangement for processing the stored image to remove imaging effects induced by the optical mask, to form an electronic image that is clearer over the extended depth of focus as compared to an electronic image that would be formed by the imaging system without the optical mask and over the extended depth of focus.

18. (Previously Presented) A method for imaging light from an object to form an image in an optical system, which light includes phase and which imaging system is characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a vertical variable v related to a misfocus parameter ψ, and which PSF is at least a function of the misfocus parameter ψ, the method comprising:

forming the image; and

detecting the image over a range of spatial frequencies,

wherein forming the image includes modifying the phase without reducing the range of spatial frequencies, such that a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively,

characterizing the imaging system without modifying the phase for those given values u and ψ, over a range of object distances between the object and the imaging system.

19. (Previously Presented) The method of claim 18, further comprising:

post-processing the image to remove imaging effects induced in the image by the modifying, to render an electronic image that is clearer over the range of object distances, as compared to an electronic image that would be formed by the imaging system if the step of forming did not include modifying phase.

20. (Previously Presented) An imaging system characterized at least by an ambiguity function and a point spread function (PSF), which ambiguity function is a function of a normalized spatial frequency parameter u and a misfocus parameter ψ, and which PSF is also a function of at least the misfocus parameter ψ, the imaging system comprising:

a lens and an optical mask that cooperate to image light from an object to form an optical image, which light is characterized by at least phase; and

a detector for detecting the optical image over a range of spatial frequencies to form a detected image,

wherein the optical mask is configured for modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u and the PSF of the system has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ and over a range of object distances from the object to the system.

21. (Previously Presented) The system of claim 20, further comprising a post-processor for processing the detected image, to remove imaging effects induced in the optical image by the optical mask and to form an electronic image that is clearer, as

compared to an electronic image that would be formed by the system without the optical mask, over the range of object distances.

22. (Previously Presented) The system of claim 20, wherein the optical mask is configured to implement a cubic phase modulation.

23. (Previously Presented) The system of claim 20 wherein the optical mask is formed integrally with the lens.

Evidence Appendix

1 Declaration of Wade Thomas Cathey, submitted under 37 CFR §1.132 on 9 May 2005, three pages (Attached hereto)

2. Tutorial of Wavefront Coding, as requested by the Examiner and supplied by Appellants in the Amendment and Response submitted 9 January 2006. (Note, as the pages submitted herewith are true copies, a passage of the Amendment and Response that does not form part of the Tutorial remains on the leading page.) (Attached hereto)

DECLARATION OF WADE THOMAS CATHEY UNDER 37 CFR §1.132

Dear Sir:

I, Wade Thomas Cathey, declare that:

1. I currently reside at 360 Alpine Way, Boulder, Colorado 80304.

2. I am an inventor named in U.S. patent application Serial No. 09/070,969, filed on 1 May, 1998 ("the '969 application"), and a continuation application thereof, Serial No. 10/758,740, filed 16 January 2004 ("the '740 application"), both applications entitled Extended Depth of Field Optical Systems.

3. I have obtained the following university degrees: B.S. (Electrical engineering, University of South Carolina, 1959); M.S. (Electrical engineering, University of South Carolina, 1961); Ph.D. (Electrical engineering, Yale University, 1963). From 1962 to 1968, I was Group Scientist in the Laser and Electro-Optics Department, Autonetics Research Center, Rockwell International Corp., Anaheim, California, where I supervised and conducted research in pattern recognition, coherent optical information processing, holography, propagation of coherent waves through the atmosphere, imaging through random media, and laser arrays. From 1968 to 1977, I was Associate Professor and then Professor of Electrical Engineering, University of Colorado, where I taught courses in optics, communications, field theory, and logic. I also performed and direct research in holography, spatial filtering, coherent optics, imaging systems and sampling theory. From 1983 to 1987 I also was the Director, of an NSF Engineering Research Center for Optoelectronic Computing Systems. From 1997 to 2003, I was a Research Professor, Electrical and Computer Engineering, University of Colorado, doing research on hybrid optical and signal processing imaging systems. I am a fellow of the Optical Society of America, the Institute of Electrical and Electronics Engineers, Fellow, and the SPIE.

4. I am a founder and currently President of CDM Optics, Inc. of Boulder, Colorado, the assignee of the '969 and '740 applications.

5. I am familiar with the official Office Actions dated 9 November, 2004 in the '969 application and dated 5 November, 2004 in the '740 application, and with the prior art references cited therein. I am for example familiar with U.S. Patent No. 4,804,249 issued to Reynolds et al. ("Reynolds").

6. An optical transfer function ("OTF") characterizes an optical system by defining the transfer function from an object point to an image. A cross-section of the OTF at the point image provides the commonly-known "point spread function." The OTF thus provides phase and blur information related to imaging capability of the optical imaging system. The convolution of the OTF with a mathematical construct of the object provides a theoretical image, which predicts the image quality of an actual image through the optical imaging system. The modulus of the OTF is called the modulation transfer function, which does not include phase information. This definition means that an OTF of a system depends on more than the numerical aperture of the lens of the system; for example the OTF also depends upon object distance, i.e., that distance between an object and the optical imaging system.

7. If an optical element is "transparent", this does not mean that there is no absorption by, or scattering or reflection from the optical element. Rather, a transparent optical element means

that the amplitude of light is generally the same after passing through the optical element (losing only a small percentage to absorption, scattering, reflection).

8. It is understood that spatial frequencies are an inherent aspect of an image, higher spatial frequencies within an image providing greater information content or clarity. The range of these spatial frequencies is defined by the optical bandpass of optics of an optical imaging system forming the image; this range being determined by the limiting aperture of the optical imaging system. An image recording device can only detect a range of spatial frequencies that passes through the optical bandpass, the highest detectable spatial frequency corresponding to the smallest angular spacing of adjacent detecting elements of the image recording device. Accordingly, if an image recording device captures an image, and if one desires to image process data from the image recording device, then this can be done only within the range of spatial frequencies that are in fact detectable by the image recording device. Therefore, in claims of the '740 and '969 applications, an optical transfer function contains no zeroes within a range of spatial frequencies detected by an image recording device.

9. Each of FIG. 10 through FIG. 15 in the '740 and '969 applications, as filed, show a range of spatial frequencies in which the OTF does not contain zeroes. This range corresponds to the optical bandpass of the optical imaging system centered about a spatial frequency of zero. FIG. 15 is for example shown below. Note that a large frequency range exists, centered about zero, in which an OTF of an optical system does not have zeroes. With this OTF, a detector can be chosen such that there are no zeros in an optical transfer function over detected spatial frequencies of the optical image.

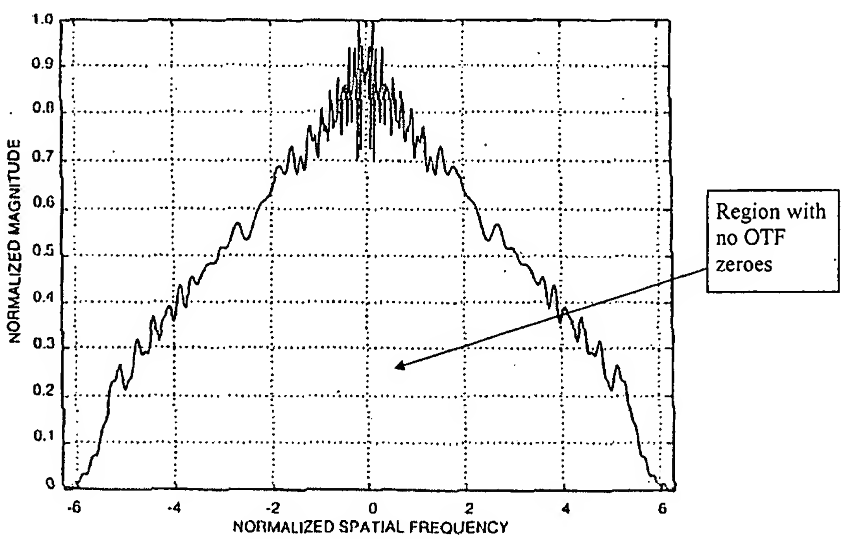


Fig. 15

10. A variable or an equation may be normalized, and that normalization may make a variable unitless. Thus the normalization of the equation that appears at page 16, line 3 in the specification of the '740 application, as filed, makes it clear that the spatial parameter x and spatial frequency parameter u are unitless.

11. Optical materials having variations in opacity, thickness, diffractive properties and/or index of refraction are known in the art of optics. It is well known, for example, that the optical element commonly known as a "zone plate" consists of a series of concentric opaque rings (i.e., variations in opaqueness) acting together to focus light. Common plano convex lenses use variations in thickness to form focused images. Holographic Optical Elements (HOEs) use diffractive structures (i.e., variations in diffractive properties) to focus images, while variations in index of refraction is demonstrated in the "Grin lens," which uses spatial variations of index of refraction to form focused images."

12. Reynolds discloses an optical filter with transparent, discrete steps, each step having a thickness that differs from all other steps by at least the coherence length of transmitted radiation. As a person skilled in the field of optics appreciates, the size of the Reynolds' lateral step determines the cut-off frequency of the optical system, thereby reducing the useful optical bandpass of the optical system as determined by the system aperture. Further, Reynolds' optical filter results in a dramatic reduction in the spatial frequency passband of the optical system, and these spatial frequencies can not be recovered by post processing.

13. Claims of the '740 and '969 applications involve modifying phase, such as by an optical phase mask. Modifying phase as described in the applications does not reduce the usable and desirable frequency range of the optical bandpass as defined by the system optical aperture. Rather, these applications extend the depth of field for which the OTF has no zeros so that a crisper image may be obtained as compared to an image without modifying phase in this way. On the other hand, the discrete steps of Reynolds in fact destroy the useful frequency range obtainable through the optical bandpass because the images cannot be coherently combined.

14. Further, the claims of the '969 application utilize post-processing, (a) to "render an in-focus electronic image" (as in claims 75, 87 and 88) or (b) for "reversing an alteration in an image induced by phase alteration" (as in claims 89 and 94) or (c) for "reversing the step of optically altering by electronically processing a digital representation of the image to increase the optical depth of field" (as in claim 99). Utilizing the optical filter described by Reynolds would thwart the actions required by these claims; that is, "an in-focus electronic image" cannot be rendered, "an alteration in an image induced by phase alteration" cannot be reversed, and "the step of optically altering" cannot be reversed, because of the permanent reduction in the passband of the optical system done by Reynolds' optical filter. Reynolds purposefully restricts the frequency range to make a low-pass filter that eliminates aliasing in the final image, thus reducing overall image clarity.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that the statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the Application or any patent issued thereon.

Respectfully submitted,

Dated: 4 May 05

Wade Thomas Cathey

New claim 19 is similar to cancelled claim 3 but depends from and conforms to the point spread function language of claim 18. The limitations recited in claim 19 are supported, for instance, in paragraph **[0094]** of the application as filed.

New claim 20 is similar to pending claim 7 but with claim limitations defined using ambiguity function and point spread function language as supported, for example, in paragraph **[0072]** of the specification as filed.

New claim 21 is similar to pending claim 8 but depends from and conforms to the point spread function language of claim 20. Such limitations are supported, for example, in paragraph **[0094]** of the application as filed.

New claim 22 adds a limitation that the optical mask is configured to implement a cubic phase modulation, as supported, for instance, by paragraphs **[0077]** – **[0080]** and FIG. 3 of the application as filed.

New claim 23 adds a limitation that the optical mask is integrally formed from the lens. This limitation is supported in the specification as filed at, for example, paragraph **[0120]** and FIG. 45.

No new matter has been added by the new claims.

Tutorial of Wavefront Coding – As Requested by Examiner Chang

The following provides a brief comparison between the art of record and the disclosure of the present application as filed, as requested by the Examiner at the Interview of December 6, 2005.

A unmodified, traditional imaging system (without Wavefront Coding (WFC)) is a good starting point for comparing imaging systems. An ideal, unmodified imaging system is understood to be one characterized by a pupil function that is constant across the aperture. An example of an unmodified imaging system is, for instance, the "standard optical system" shown in Figure 1 of the application as filed, including a lens 25 for imaging an object 15 therethrough onto a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) sensor 30.

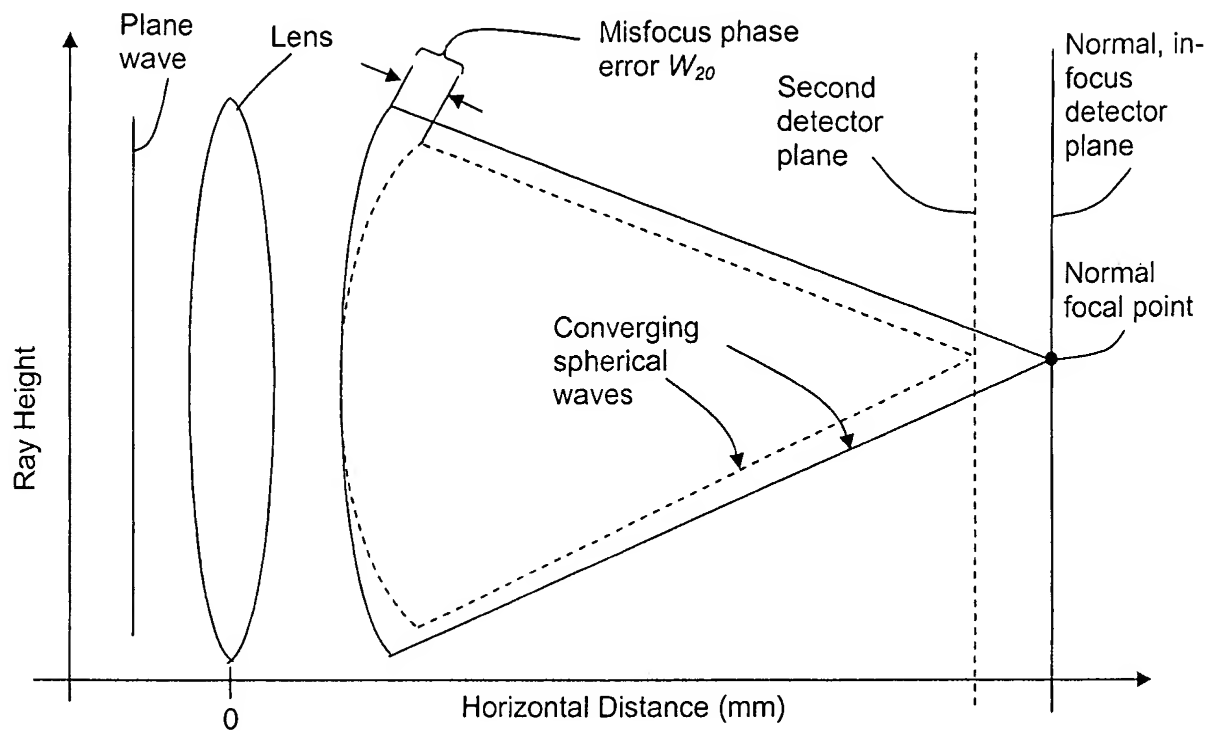


FIG. 1. Phase difference of two converging spherical waves.

Another example is shown in FIG. 1 above. This type of system is also referred to as a diffraction-limited imaging system in the optics literature. A diffraction-limited system is known in the art to be an ideal system. Such an ideal system is essentially impossible to construct in practice due to the presence of numerous aberrations, or non-ideal characteristics, in real imaging systems. However, these aberrations, if small enough, are often ignored when considering theoretical performance of an imaging system.

FIG. 1 shows a plane wave focused by a lens, and illustrates the phase error that results when the detector plane is moved closer to a one-dimensional lens from the normal focal point. A perfect lens will produce a spherical wave (indicated by dashed lines) that focuses to a point, shown as the normal focal point in FIG. 1, and an in-focus image would result at the normal detector plane. If the detector plane is moved closer to the lens (e.g., away from the best focus position to the position of the second detector plane in FIG. 1), the spherical wave that would converge to the new location must be more curved (as indicated by solid lines). The phase difference between these two spherical waves at their extreme ends is referred to as a misfocus

phase error, also known as aberration W_{20}, as first described by Hopkins (H.H. Hopkins, "The Aberration Permissible in Optical Systems," Proc. Phys. Soc. LXX, 5 – B, 1957, pp. 449 – 470). The "2" in the subscript of the misfocus phase error refers to a quadratic function in radius, and the "0" in the subscript refers to no variations in angle, in a cylindrical co-ordinate system. W_{20} is related to a misfocus parameter ψ by the equation:

$$\psi = 2\pi \frac{W_{20}}{\lambda} \quad \text{(Eq. 1)},$$

where λ is the wavelength of the light rays.

In general, for a given imaging system (e.g., a lens with a lens length L, a focal length f with a given object distance d_o and image distance d_i for imaging light with wavelength λ), the misfocus parameter ψ is given by the equation:

$$\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right) \quad \text{(Eq. 2)}$$

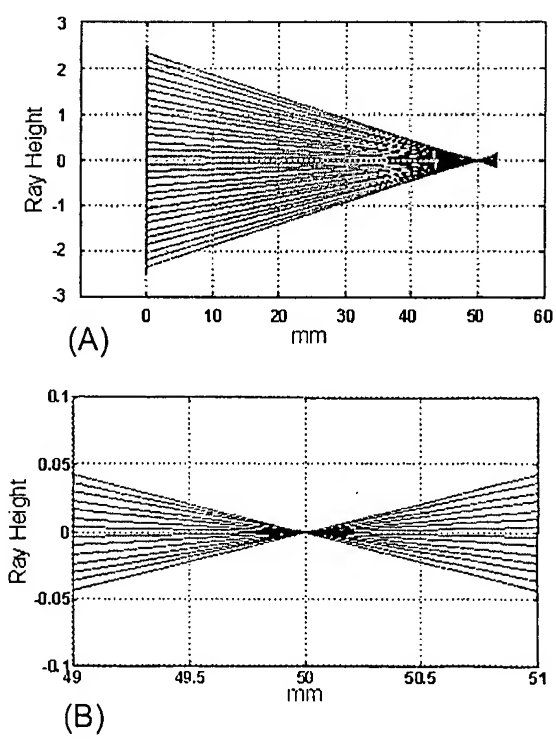


FIG. 2. Propagating rays through an unmodified, one-dimensional lens located at 0 mm, illustrated as a plot of ray height as a function of horizontal position.

Ideal light rays approaching the lens of FIG. 1 propagate perpendicular to the wave front, and come to a focus as shown in FIG. 2(A). FIG. 2(B) shows the details of the ray convergence at the horizontal position of 50 mm of the rays of FIG. 2(A).

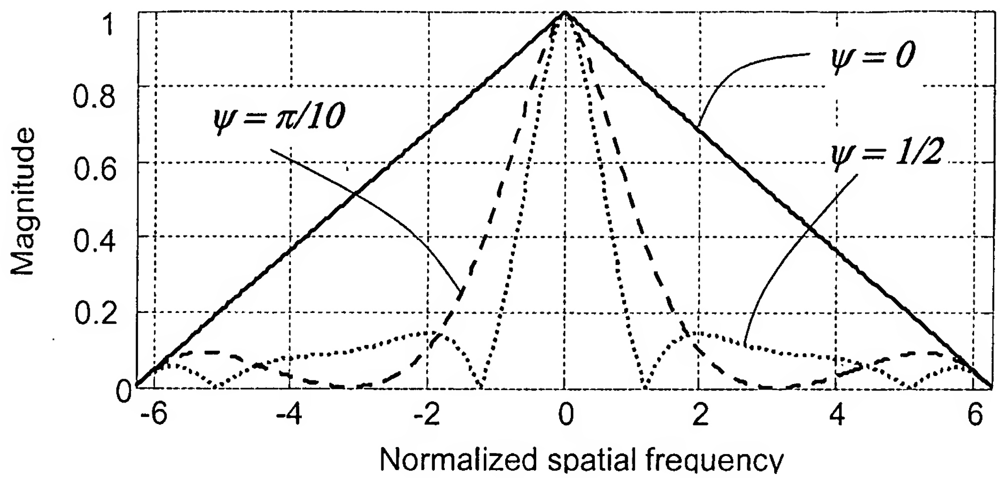


FIG. 3. OTF of an unmodified imaging system for three values of misfocus parameter.

The Fourier transform of the PSF of an imaging system results in an optical transfer function (OTF) of the imaging system as a function of spatial frequency (e.g., in units of cycles per mm). The magnitude of the optical transfer function is called the modulation transfer function (MTF), which is related to the effect of the imaging system on the magnitude of the spatial frequencies of the information traveling from the object, through that imaging system and to the detector plane. The OTF of the unmodified, traditional imaging system as a function of normalized spatial frequency u, for three values of misfocus parameter ψ is shown in FIG. 3. Note that the curves corresponding to values of $\psi = 0$ and $\psi = 1/2$ correspond to Fig. 6 and Fig. 7, respectively, of the application as filed. It is noted that the maximum theoretical range of the normalized spatial frequency ψ is $\pm 2\pi$.

A one-dimensional pupil function system (such as the normalized one-dimensional pupil function $\hat{P}(x)$ for normalized spatial parameter x as discussed on pages 15-16 of the application

as filed) is considered herein for simplicity. Extensions of the presently considered concepts to two dimensions have equivalent fundamental properties; that is, for example, an imaging system with a rectangular aperture may be considered as a combination of two, one-dimensional systems. As described near the top of page 16 of the application as filed, the OTF for a general imaging system for a one-dimensional pupil function is given by:

$$H(u,\psi) = \int \left(\hat{P}\left(x + \frac{u}{2}\right) e^{i\left(u+\frac{x}{2}\right)^2 \psi} \right) \left(\hat{P}^{*}\left(x - \frac{u}{2}\right) e^{-i\left(u-\frac{x}{2}\right)^2 \psi} \right) dx \qquad \text{(Eq. 3)}$$

As may be seen in FIG. 3, the OTF of an unmodified, one dimensional imaging system with zero misfocus ($\psi = 0$) has a triangular shape (as also shown in Fig. 6 of the application as filed). The notable feature of the OTF of the unmodified, ideal imaging system with zero misfocus is that the magnitude of the OTF does not exhibit any zeros (i.e., spatial frequencies at which the magnitude of the OTF is zero) within a given range of normalized spatial frequency values ($-2\pi < u < 2\pi$, in the example shown in FIG. 1). This feature of the ideal OTF exhibiting non-zero magnitude over a range of normalized spatial frequency values is particularly attractive because it indicates that no image spatial frequency information is lost during the imaging process by this ideal imaging system for images in this range of normalized spatial frequency values.

Aberrations in an imaging system act to decrease the magnitude of the OTF at particular spatial frequencies. These aberrations may be misfocus-like aberrations, such as misfocus, astigmatism, spherical aberrations, astigmatism or chromatic aberration, or other aberrations like coma. For example, for a small amount of misfocus (e.g., $\psi = \pi/10$ as shown in FIG. 3) the OTF may decrease overall while going to essentially zero at two values of normalized spatial frequency within the range of normalized spatial frequencies shown in the figure. As may be seen in FIG. 3, the OTF for this small value of misfocus ($\psi = \pi/10$) is dramatically different from the OTF for zero misfocus ($\psi = 0$). In the case of mild misfocus ($\psi = \pi/10$), the range of normalized spatial frequency over which the OTF exhibits no zeros (i.e., the width of the main OTF peak) has been reduced to $-3 < u < 3$, indicating that image information for images having spatial frequencies outside of this range would be lost during the imaging process through this imaging system with mild misfocus.

For larger amounts of misfocus (such as $\psi = 1/2$), the OTF may exhibit numerous zeros within the range of normalized spatial frequencies shown while the width of the main OTF peak is further narrowed (also see Figure 7 of the application as filed). Figure 8 of the application as filed shows the OTF for an even greater value of misfocus ($\psi = 3$), which exhibits numerous values of normalized spatial frequency where the magnitude of the OTF is essentially zero.

While the OTF gives an accurate characterization of the modulation of an imaged object as a function of spatial frequency, a particular OTF curve gives information only for a given value of misfocus. Another characterization tool for imaging systems is the Ambiguity Function (AF). The AF, first proposed by P. M. Woodward (P. M. Woodward, *Probability and Information Theory with Applications to Radar*, Pergamon, New York, 1953), may be interpreted as a visualization of the OTF of an imaging system for all values of misfocus for a range of normalized spatial frequency values on the same plot. That is, the modulation of the imaging system for all values of misfocus may be qualitatively evaluated by visual inspection of the AF. Specific systems may also be designed efficiently and accurately through quantitative evaluation of the AF. The AF is related to the OTF by the following equation:

$$H(u,\psi) = A\left(u, \frac{u\psi}{\pi}\right) \qquad \text{(Eq. 4)}$$

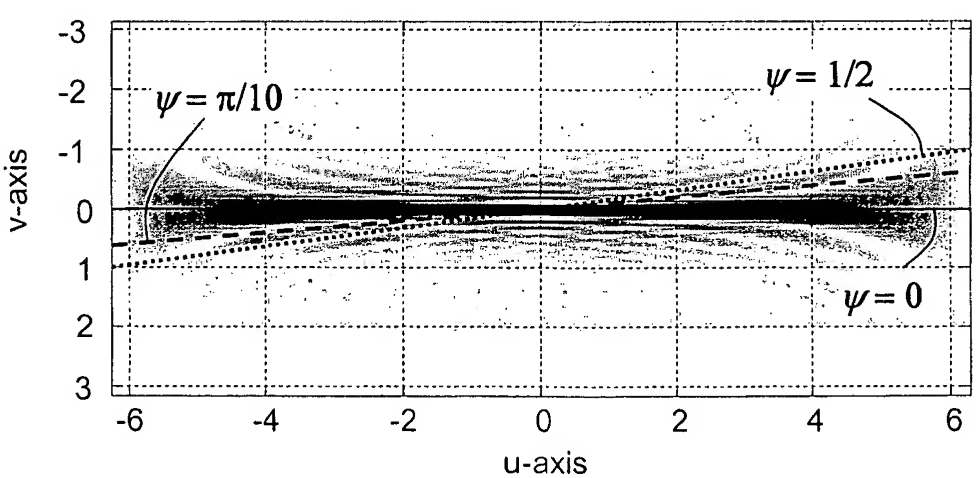


FIG. 4. AF of an unmodified, traditional imaging system

The AF related to the pupil of a unmodified, traditional imaging system is shown in FIG. 4. This figure is essentially the same as Fig. 5 in the application as filed. The AF was originally developed as a tool to analyze radar systems. It is common to label the axes of the AF as u-axis for the horizontal axis and v-axis for the vertical axis. In terms of an imaging system, the u-axis represents spatial frequency analogous to the horizontal axis of OTF plots. While the vertical axis has no direct relationship to imaging systems, the projection of radial slices of the AF onto the horizontal axis may be interpreted as the OTF of this imaging system for various amounts of misfocus. That is, the AF shown in FIG. 4 may be interpreted as a three-dimensional function, with the density of the grayscale indicating the height out of the page (i.e., darker shades corresponds to higher OTF magnitude), the horizontal axis representing a normalized spatial frequency, and the angle measured from the horizontal axis corresponding to the misfocus parameter ψ.

The AF is useful because it enables the visualization, in a single graphic, of the range of OTFs for a one-dimensional imaging system through a range of object and/or image distances. That is, the AF may be regarded as a plot of OTFs arranged in a radial fashion where the angle between a radial line and the horizontal axis determines the degree of misfocus of the OTF. For example, a horizontal slice of the AF, or a radial line through the origin with a slope of zero, corresponds to the OTF with zero misfocus.

For a given value of normalized misfocus ψ, the slope of the radial line that produces the OTF with that amount of misfocus is given by ψ/π. The projection to the u-axis of the AF modulation under the radial lines labeled $\psi = 0$, $\psi = \pi/10$ and $\psi = 1/2$ of FIG. 4 yield exactly the OTFs with misfocus values $\psi = 0$, $\psi = \pi/10$ and $\psi = 1/2$ as shown in FIG. 3. It may be observed by inspection of FIG. 4 that, for increasingly larger values of ψ (i.e., for radial lines with larger slope), the modulation of the AF will continue to fall. That is, the lighter shading of the AF away from the horizontal axis indicates reduced modulation of the AF (where the horizontal, $v = 0$ axis corresponds to the misfocus value $\psi = 0$).

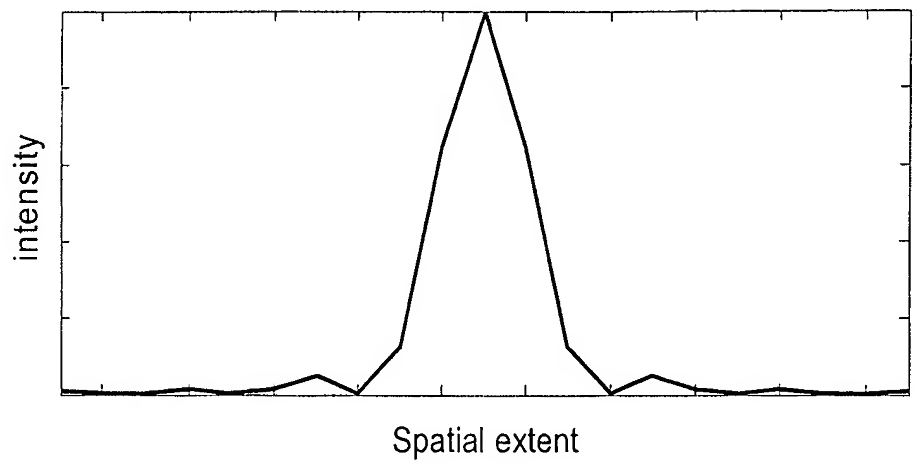


FIG. 5. Calculated PSF of an unmodified, traditional imaging system with no misfocus.

FIG. 5 shows a calculated PSF of the unmodified, traditional imaging system with zero misfocus. FIG. 5 corresponds to Fig. 17 of the application as filed, except for the choice of horizontal and vertical scales, and resolution of the data plotted. As noted earlier, the PSF is related to the OTF through a Fourier transform. Therefore, the PSF of the unmodified, traditional imaging system with zero misfocus is obtained by calculating the inverse Fourier transform of a triangle function as shown in FIG. 3. From knowledge of Fourier transform relationships, it is readily deduced that the functional form of the PSF is then a *sinc*-squared function, where the *sinc* function is defined as: $sinc = (1/x)\sin(x))$; and the *sinc*-squared function is $sinc^2 = (1/x^2)(\sin(x))^2$. It is known that, if the imaging system exhibits aberrations, then the OTF is no longer a triangular function and the PSF is no longer a *sinc*-squared function. However, it is emphasized that the PSF of the unmodified, traditional imaging system with zero misfocus has the functional form of a *sinc*-squared function.

Stopped Down Imaging Systems

A stopped down imaging system is related to a traditional unmodified imaging system but with a reduced aperture size. The reduction of the aperture size results in decreased sensitivity of the system to misfocus, reduced spatial resolution of the optics and decreased amount of light gathered by the imaging system. The functional form of the stopped down zero

misfocus PSF is substantially the same (i.e., having only a scale change) as the zero misfocus, unmodified traditional imaging system.

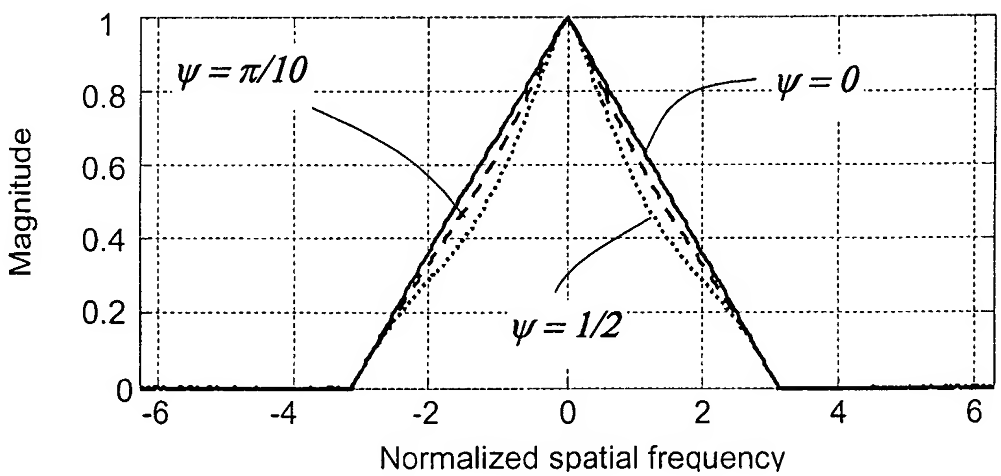


FIG. 6. OTFs of a stopped down imaging system for three values of misfocus.

FIG. 6 shows the OTF of a stopped down imaging system with three different values of misfocus, corresponding to those shown in FIG. 3. The aperture has been reduced to one-half of the unmodified, traditional imaging system discussed earlier. While FIGS. 3 and 6 are shown to be normalized to one, in practice, the OTF peak falls as the square of the ratio of the diameters of the stopped-down and the full aperture. The peak of the non-normalized OTF at zero spatial frequency is equal to the area under the PSF curve, and is related to the number of photons captured by the lens.

There are two important differences between the OTFs of the traditional unmodified system of FIG. 3 and the stopped down system of FIG. 6. First, the OTFs for the stopped down system vary much less than those of the full aperture, unmodified system for the same values of ψ. The second important difference is that the magnitude of the OTF of the stopped down system is substantially zero beyond a normalized spatial frequency value of π. This second difference is due to the fact that the size of the aperture of the stopped down system is one-half that of the full aperture system. This reduction of the aperture size by a factor of two leads to a loss of intensity (i.e., photons) at the image plane. This intensity loss is not seen in the

normalized vertical axes of the OTFs of FIG. 6. In a two-dimensional system with a square aperture, for example, the intensity loss would be by a factor of four.

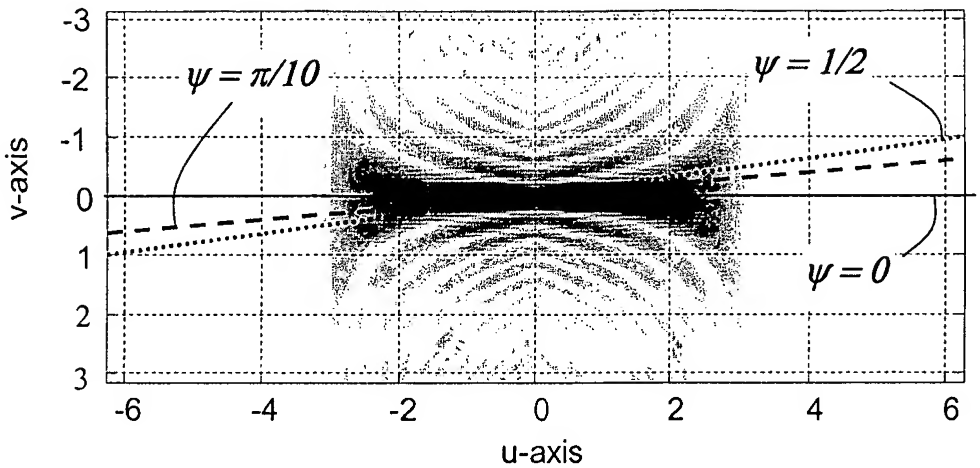


FIG. 7. AF of an unmodified, traditional imaging system that has been stopped down by a factor of two.

The AF related to the stopped down imaging system is shown in FIG. 7. There are again two main differences between the AFs of the stopped down system and the traditional unmodified system as shown in FIG. 4. First, the main lobe (i.e., the dark region near the $v = 0$ line) of the AF of the stopped down imaging system is slightly broader or wider in the v-direction for a given value of u than the main lobe AF of the traditional unmodified imaging system for a given value of misfocus. That is, the central dark region of the AF of the stopped down system in FIG. 7 around the $v = 0$ line is slightly broader or wider in the vertical direction for a given u-axis value (i.e., normalized spatial frequency value) than in the traditional unmodified system as shown in FIG. 4. In other words, radial lines of steeper slope, corresponding to larger values of misfocus ψ, are required to intersect the light regions of the AF such that the OTF includes zeros, as compared to in the AF of the unmodified, traditional system. In such cases, when the AF of the stopped down imaging system is slightly broader in the misfocus domain compared to the unmodified traditional system, the modified, stopped down system will exhibit a slightly reduced sensitivity to misfocus. However, there is still a significant concentration of the AF intensity in the immediate vicinity of the $v = 0$ line.

The other main difference between the AFs of the stopped down and unmodified system is the horizontal extent of the AF. It may be seen in FIG. 7 that the horizontal extent of the stopped down AF is ½ as large as that of the unmodified, traditional system. In the example illustrated in FIG. 7, the horizontal extent of the AF of the stopped down system is exactly one half as large as that of the full aperture unmodified system. That is, the spatial resolution of the stopped down system is reduced accordingly.

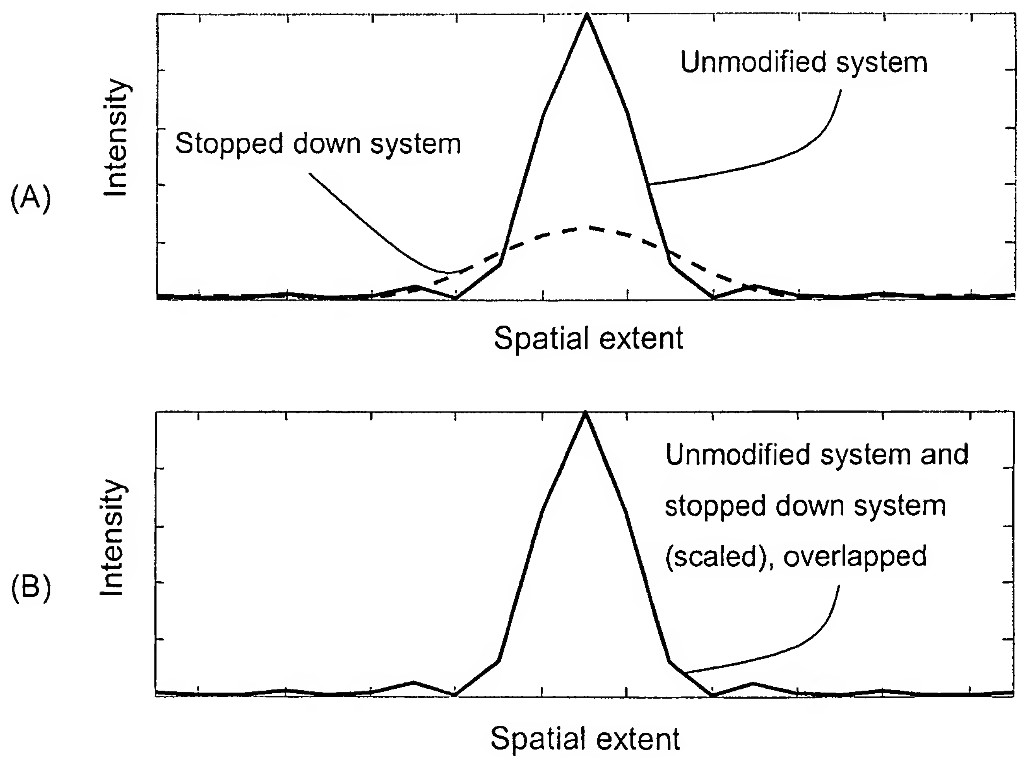


FIG. 8. A comparison of the PSFs of the unmodified, traditional imaging system and the stopped down, modified system for zero misfocus ($\psi = 0$). FIG. 8(A) does not include scaling, and FIG. 8(B) includes scaling of the PSF of the stopped down system in both the horizontal and vertical directions.

The zero misfocus ($\psi = 0$) PSF of the stopped down system is compared with that of the unmodified, traditional imaging system in FIGS. 8(A) and 8(B). As may be seen in FIG. 8(A), the PSF of the stopped down, zero misfocus imaging system is, at first glance, wider horizontally

and shorter vertically than that of the zero misfocus PSF of the unmodified, traditional imaging system, which was earlier shown in FIG. 5. The increased width of the stopped down system PSF is due to the decrease in the horizontal extent of the AF and OTF of the stopped down system over those of the unmodified, traditional imaging system. The PSF of the stopped down system is shorter vertically (i.e., is reduced in intensity) as compared to that of the unmodified system because the reduced aperture allows only ½ of the number of photons into the stopped down system as compared to in the unmodified, full aperture system. In other words, the sum of all the PSF values for a particular value of misfocus for the ideal, stopped down system is one half that of the sum of the all the PSFs values for the same value of misfocus for the ideal, unmodified, traditional imaging system.

It is notable, however, that the aperture size of the full aperture, unmodified, traditional imaging system is arbitrary. That is, the stopped down system presently under discussion may be considered as a scaled version of the unmodified, traditional imaging system. This fact implies that the functional form of the PSF of an unmodified, traditional imaging system is independent of the size of the aperture.

In general, if a given imaging system exhibits a particular PSF having a mathematical form of:

$$PSF_0(x) = h(x) \qquad \text{(Eq. 5)},$$

where x is an independent spatial variable, then another PSF (e.g., PSF_1) may be characterized as having the same functional form as PSF_0 if:

$$PSF_1(x) = a \cdot h(bx) \qquad \text{(Eq. 6)}$$

for some non-zero constants a and b.

In comparing FIGS. 3 and 6, it may be seen that the OTF of the zero misfocus, stopped down imaging system has a triangular form with one half the width and one half the total sum (i.e., the area under the OTF curve) of the unmodified, traditional imaging system with zero misfocus. From knowledge of the properties of the Fourier Transform, it may be deduced that the spatial dimension of the PSF of the stopped down system is twice as broad and the maximum PSF intensity is one fourth as large as those of the unmodified, traditional imaging system.

Therefore, the functional form of the PSF of a one-dimensional, stopped down system with aperture one half of the unmodified, traditional imaging system may be expressed as:

$$PSF_{\text{stopped\_down}}(x) = \frac{1}{4} PSF_{\text{unmodified}}\left(\frac{1}{2}x\right) \qquad \text{(Eq. 7)},$$

i.e., $a = ¼$ and $b = ½$ in (Eq. 6). Generally, for a one-dimensional, stopped down system with aperture size S, where $S \le 1$, the functional form of the PSF of this stopped down system may be expressed in terms of the PSF of the unmodified, traditional imaging system as:

$$PSF_{\text{general\_stopped\_down}}(x) = S^2 \cdot PSF_{\text{unmodified}}(S \cdot x) \qquad \text{(Eq. 8)}.$$

In the present example, the PSF of the stopped down system (the dashed curve in FIG. 8(A)) is related to the PSF of the unmodified, traditional imaging system by (Eq. 7). Consequently, as shown in FIG. 8(B), the PSF of the stopped down system may be scaled vertically and horizontally such that the scaled PSF of the stopped down system overlaps the PSF of the unmodified, traditional system. In other words, the PSF of the stopped down system has the same *sinc*-squared, functional form as the PSF of the unmodified, traditional system.

Stepped Phase Imaging Systems

A stepped phase imaging system is essentially a series of stopped down systems that are arranged to form statistically independent images on the same image plane. The spatial resolution is determined by the size of an individual step while the total number of photons collected by the imaging system is determined by the collective size of the steps.

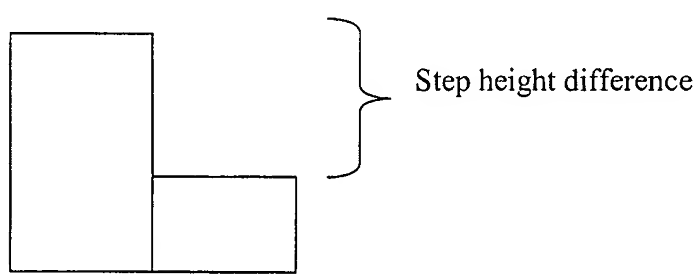


FIG. 9. Aperture layout of a two-level, stepped phase system.

FIG. 9 shows the aperture layout of a two-level, stepped phase system. Each step in FIG. 9 is shown to be optically flat, and the difference in step height is assumed to exceed the coherence length of the illumination such that the steps may be referred to as incoherent steps. If the aperture includes more than two steps (e.g., in a two-dimensional system including four steps), then the smallest difference between any two steps must exceed the coherence length of the illumination. When the step height difference exceeds the coherence length of the illumination, the light that passes through a particular step is statistically incoherent with the light passing through any other step. This incoherence allows the imaging aperture corresponding to each step to form a sub-image independent of all other regions of the aperture. The image formed at the image plane is then the composite of these sub-images.

The fundamental image forming properties of a stepped phase system are determined by the linear size (in two dimensions) of each incoherent step. The total number of photons collected by the system is determined by the total area of all incoherent steps, which is the total area of the aperture. For the one-dimensional system of FIG. 9, for example, each incoherent step occupies one-half of the aperture. The corresponding OTFs and AF of this stepped phase system of FIG. 9 are then the same as those shown for the stopped down system of FIGS. 6 and 7, respectively, since each incoherent step acts as an independent, stopped down ½ aperture imaging system. It is noted that, since the intensity axes of the AF and OTF of FIGS. 7 and 8, respectively, are normalized, the actual intensity difference between a single stopped down aperture and the two incoherent steps of the stepped phase system cannot be directly compared using these particular plots. However, it may be deduced that the insensitivity of the AF and OTF to misfocus and the reduction of the horizontal extent of the AF and OTF for the two-level, stepped phase system are the same as those of the one-half aperture, stopped down system, again since each incoherent step acts as an independent, stopped-down ½ aperture system.

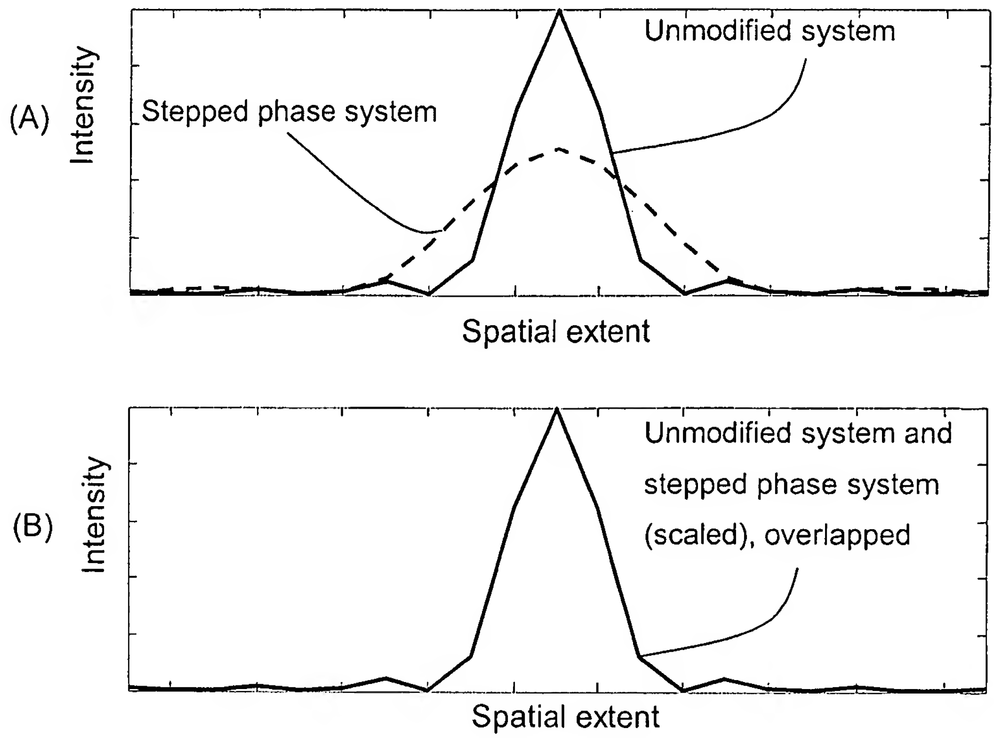


FIG. 10. A comparison of the PSFs of the unmodified, traditional imaging system and the modified, stepped phase system for zero misfocus ($\psi = 0$).

Referring now to FIGS. 10(A) and 10(B) in conjunction with FIGS. 5, 8(A) and 8(B), it is shown that the functional form of the PSF of the two-level, stepped phase system is the same as those given in (Eq. 5) and (Eq. 6) and does not differ from the PSF of the one-half aperture stopped down system in appearance. That is, there is only an intensity difference between the PSFs of: a) the unmodified, traditional imaging system; b) the stopped down system; and c) the stepped phase system.

It was earlier shown in FIGS. 8(A) and 8(B) that the PSF of the stopped down system has the same functional form of a *sinc*- squared function as the PSF of the unmodified, traditional system. Similarly, the unscaled and scaled PSFs of the stepped phase system are shown in comparison with the PSF of the unmodified, traditional system in FIGS. 10(A) and 10(B). The PSF of the stepped phase system for zero misfocus ($\psi = 0$), shown in FIG. 10(A), may be compared with the zero misfocus PSF of the stopped down system shown in FIG. 8(A). It may

be seen that the locations of the first zeros on the PSFs of the stepped phase system and the stopped down systems are the same but the maximum intensity of the stepped phase system is twice that of the stopped down system. This difference in maximum intensity between the PSFs of the stepped phase system and that of the stopped down system is due to the smaller total aperture size of the stopped down system.

From the properties of the Fourier Transform, the relationship between the PSF of the stepped phase system and the PSF of the unmodified, traditional imaging system may be expressed as:

$$PSF_{\text{stepped\_phase}}(x) = \frac{1}{2} PSF_{\text{unmodified}}\left(\frac{1}{2}x\right) \qquad \text{(Eq. 9).}$$

That is, the functional form of the PSF of the stepped phase system is the same, *sinc*- squared functional form as the PSF of the unmodified, traditional imaging system. In terms of (Eq. 6), the PSF of the stepped phase system is related in functional form to the PSF of the unmodified, traditional imaging system with constants $a = b = \frac{1}{2}$.

FIG. 10(B) shows the scaling of the PSF of the stepped system in both the horizontal and vertical directions, thus further indicating that the functional form of the PSF of the modified, stepped phase system is the same as that of the unmodified, traditional imaging system. As it was shown earlier that the functional form of the PSF of the stopped down system is also the same as that of the unmodified, traditional imaging system, it is therefore shown that the functional form of the PSFs of the stepped phase system, the stopped down system and the unmodified, traditional imaging system are all the same *sinc*-squared function.

Wavefront Coded (WFC) System

Applicants have disclosed, in the present application as filed, techniques for extending the depth of field of optical systems by incorporating a special purpose optical mask into the optical system. Such a special purpose optical mask may, for example, add a cubic phase function to light propagating therethrough.

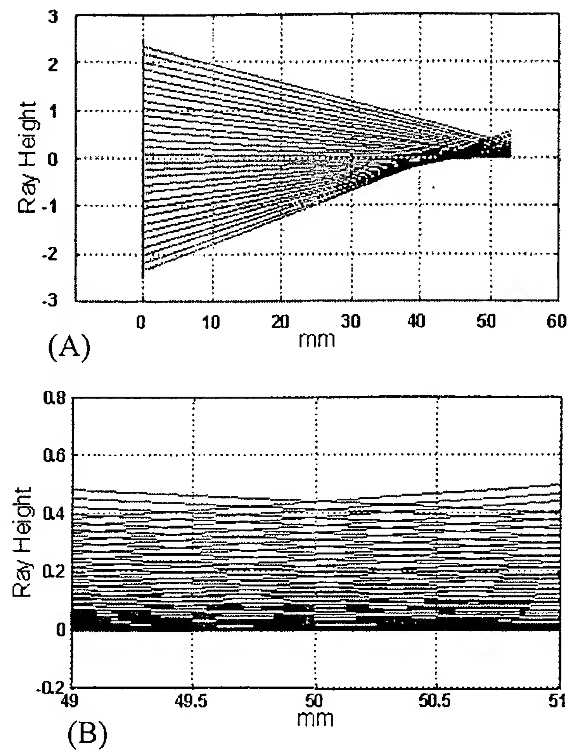


FIG. 11. Propagating rays through a WFC one-dimensional lens located at 0 mm, illustrated as a plot of ray height as a function of horizontal distance.

The ray propagation through an exemplary one-dimensional lens with an added cubic phase function is illustrated in FIG. 11(A), with the details around the former point of convergence at a horizontal distance of 50 mm shown in FIG. 11(B). The rays shown in FIGS. 11(A) and 11(B) are for an ideal one-dimensional lens with an added cubic phase function. As may be seen in comparing FIGS. 11(A) and 11(B) with FIGS. 2(A) and 2(B) for the unmodified, one-dimensional lens, the addition of the cubic phase function to the lens affects the ray propagation therethrough such that the rays do not converge at a point. This effect of the cubic phase function provides unexpected advantages, as described in detail in the present application as filed in, for example, paragraphs [0080] through [0082].

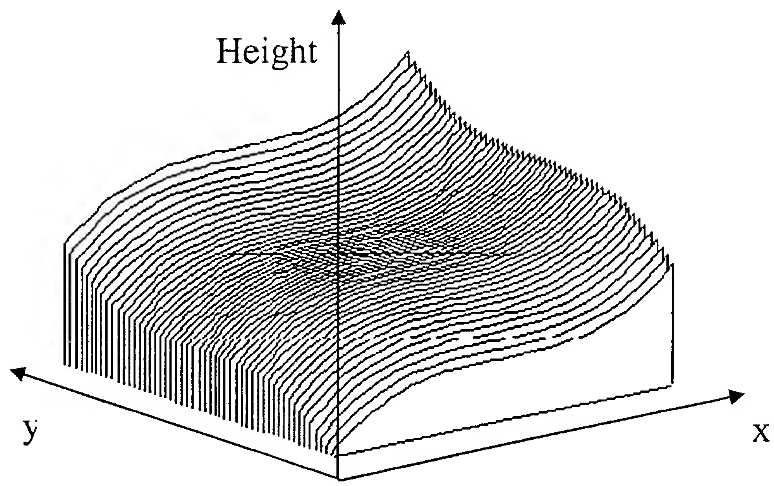


FIG. 12. The profile of a cubic phase function.

FIG. 12 shows the height profile of an exemplary cubic phase function suitable for use in the special purpose optical mask (e.g., as described in the present application as filed), illustrating the phase change that is added to a converging spherical wave traveling therethrough. The equation for the height of the function shown in FIG. 12 is $height = a\ (x^3 + y^3)$, where a is a constant that determines the maximum distance from the highest point to the lowest point. If a cubic phase function, as shown in FIG. 12, is placed on or near the one-dimensional lens, the rays no longer converge at a focal point, but take the paths shown in FIGS. 11(A) and 11(B). This process of modifying the wavefront of light traveling through an optical system with a predetermined phase function is one example of Wavefront Coding (WFC).

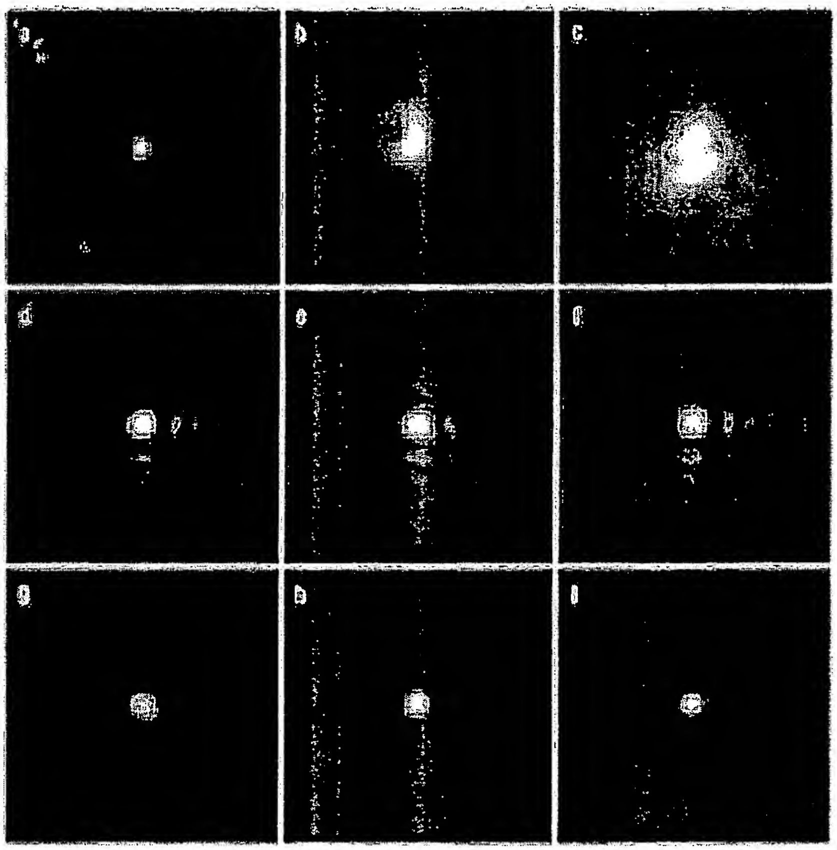


FIG. 13. Top row: images from a traditional microscope, middle row: images from a WFC microscope, and bottom row: processed images from a WFC microscope.

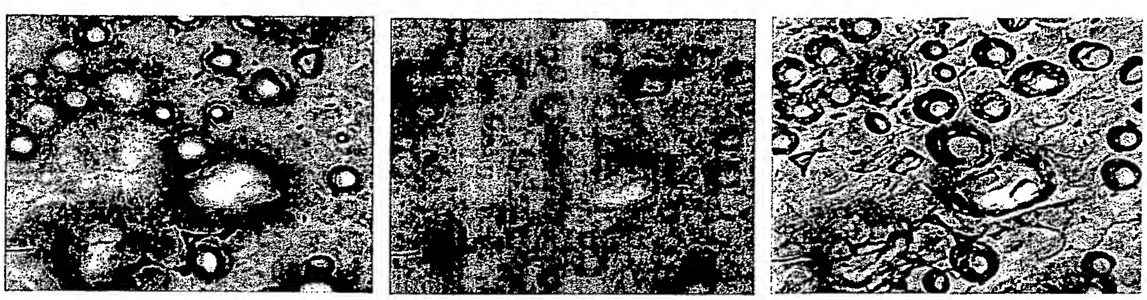
FIG. 13 shows a series of images of a point formed with a microscope without and with WFC. In the parlance of the art, these images are often referred to as point spread functions (PSFs), which correspond to the response of a given optical system to a point object and help characterize that given optical system. The top row (FIGS. 13(a) through 13(c)) shows experimental images of a point source obtained with a unmodified, traditional microscope when the detector array is moved away from the best focus position (as shown in FIG. 13(a)) to positions yielding out-of-focus images (FIGS. 13(b) and 13(c)). While effects due to a variety of aberrations are present in these experimental results, the major factor for the reduction in image quality is misfocus.

The middle row of FIG. 13 (i.e., FIGS. 13(d) through 13(f)) shows the corresponding images of a point source when WFC is included in the microscope and the detector array is

moved from the in-focus position (as shown in FIG. 13(d)) to the same out-of-focus positions of FIGS. 13(b) and 13(c) (shown in FIGS. 13(e) and 13(f)). In the present example, the two-dimensional cubic function shown in FIG. 12 is used in the WFC process. As may be seen in comparing FIGS. 13(d) through 13(f), the addition of WFC results in a substantially uniform series of PSFs even when the detector in the microscope is moved away from the plane of best focus. This result is in contrast with the images obtained with the unmodified, traditional microscope, which yields drastically varying PSFs depending on the position of the detector.

The present application as filed further provides post-processing the WFC image data in order to further improve image quality for a range of object and/or image distances (See, for example, paragraph [0094]). The post-processing may be performed in several ways. For example, the WFC image may be deconvolved with the point spread function to obtain the final image, or the Fourier transform of the image may be divided by the optical transfer function of the modified imaging system.

The bottom row of FIG. 13 (i.e., FIGS. 13(g) through 13(i)) shows the PSFs after signal processing of the WFC images of the middle row of FIG. 13. In this case, the same digital processing filter is applied to all three images of FIGS. 13(d) through 13(f) to result in the PSFs shown in FIGS. 13(g) through 13(i), respectively. It may be seen, in comparing the PSFs shown in FIGS. 13(a) through 13(c) with the PSFs obtained with WFC shown in FIGS. 13(d) through 13(i), that the effects of misfocus may be virtually eliminated with the inclusion of WFC in the optical system.



(A) (B) (C)

FIG. 14. (A) Image of a set of microscopic bubbles with a traditional microscope; (B) the same image with a WFC microscope; and (C) the same WFC microscope image after post- processing.

In some cases, it may not be necessary to perform post-processing of the WFC image to obtain the desired information. For example, if the goal is simply to determine the presence, location and number of the bubbles of FIG. 14, the processed image shown in FIG. 14(C) may not be needed. In the example shown in FIGS. 14(A) through 14(C), the image obtained with a traditional microscope shown in FIG. 14(A) may not yield the required information, since some of the bubbles are not imaged in sufficient resolution to be counted. However, the unprocessed, WFC image shown in FIG. 14(B), while not giving as clear an image as the post-processed, WFC image of FIG. 14(C), may provide all of the information required for a particular application.

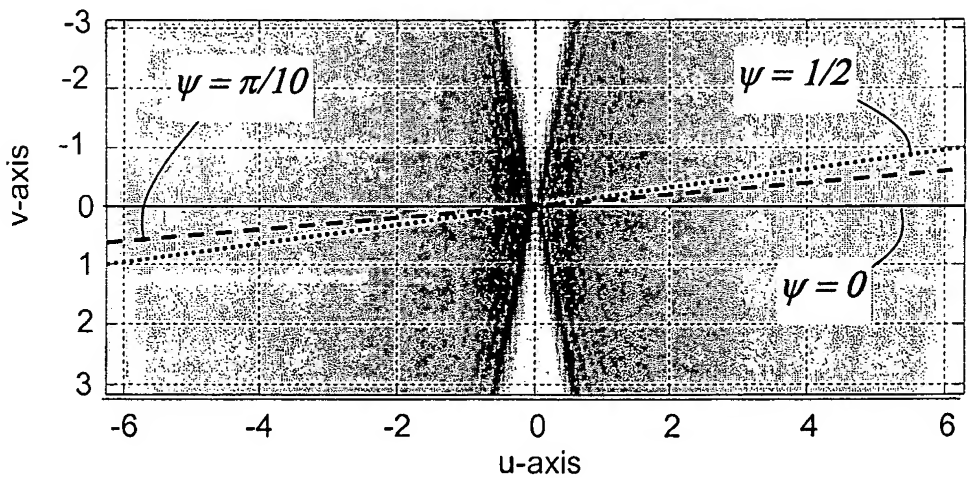


FIG. 15. AF of a WFC, cubic phase system.

FIG. 15 shows the AF for a one-dimensional, WFC imaging system including the cubic phase function shown in FIG. 12. In comparing FIG. 15 with the previously discussed FIG. 4 showing the AF for the unmodified, traditional imaging system, it may be noted that the darker, higher intensity region extends over a larger angle away from the horizontal, v = 0 axis. That is, for any given, non-zero value of the spatial frequency parameter u, the main lobe (i.e., the large, gray region above and below the $v = 0$ line) of the AF of the WFC, cubic phase system is very

broad in the v-direction in comparison to the unmodified, traditional imaging system such that the WFC imaging system including the added cubic phase exhibits a larger depth of field.

Continuing to refer to FIG. 15, as explained earlier, darker shades in the ambiguity function plot indicate higher magnitude of the ambiguity function. Upon examination of FIGS. 4 and 7, it may be seen that, for a line traversing the ambiguity function corresponding to non-zero values of misfocus ψ, the magnitude distribution of the ambiguity function for an unmodified, traditional imaging system and the stopped down system are still quite narrow compared to the AF shown in FIG. 15 because most of the power in the ambiguity function plots is concentrated along the v = 0 axis. In contrast, as the power of the ambiguity function for a WFC imaging system is more uniformly distributed, the magnitude distribution of the ambiguity function for the WFC imaging system is broader along any given line traversing the ambiguity function for non-zero values of misfocus ψ without reduction in spatial resolution. That is, while the main lobe, or the region of high magnitude (i.e., the darker region), of the AF of the unmodified, traditional imaging system is concentrated along the v = 0 axis, the main lobe of the AF of the WFC imaging system is spread throughout a larger portion of the entire AF plot over a larger range of misfocus parameter ψ.

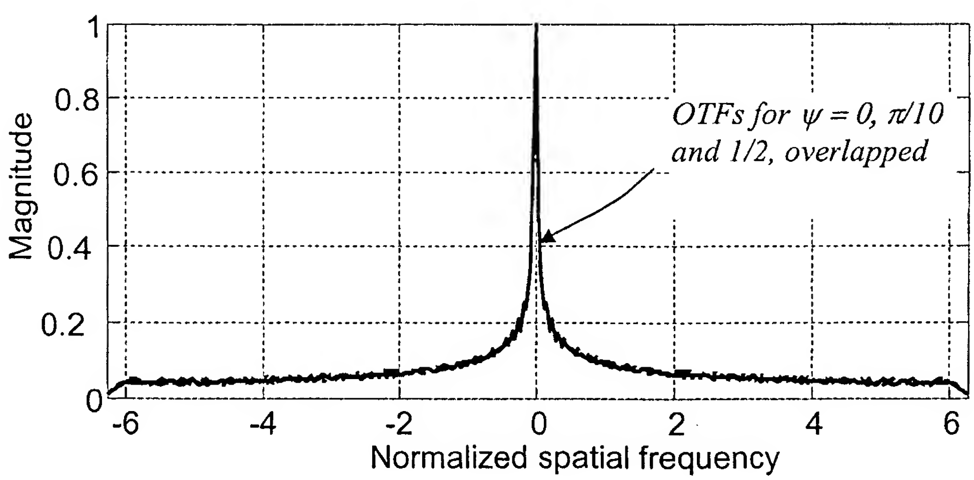


FIG. 16. OTFs of a WFC, cubic phase system for three values of misfocus.

The traces through the AF shown in FIG. 15 for the WFC imaging system for three different values of misfocus, namely for $\psi = 0$, $\pi/10$ and ½, are shown in FIG. 16. As may be

seen in FIG. 16, the WFC imaging system exhibits substantially the same OTF for these values of misfocus (note that the curves in FIG. 16 corresponding to $\psi = 0$ and ½ are the same curves as shown in Fig. 10 and Fig. 12 of the present application.) In other words, the OTF is essentially constant over this range of misfocus, and, the WFC system is invariant to misfocus over the normalized spatial frequency range of $\pm 2\pi$. Also, since the OTFs shown in FIG. 16 correspond to cross sections of the AF shown in FIG. 15, these OTFs illustrate the broadening of the main lobe of the AF, as the central non-zero portions of the OTFs (around the $u = 0$ axis and corresponding to cross sections of the main lobe of the AF) now extend over the normalized spatial frequency range of $\pm 2\pi$ for even non-zero values of misfocus parameter ψ. That is, in comparing the OTFs of the WFC imaging system as shown in FIG. 16 with the OTFs of the unmodified, traditional imaging system as shown in FIG. 3, for example, it may be seen that the central non-zero portion of the OTFs (corresponding to cross sections of the main lobe of the AF) for non-zero values of misfocus are significantly broader in the WFC system as compared to the unmodified, traditional imaging system.

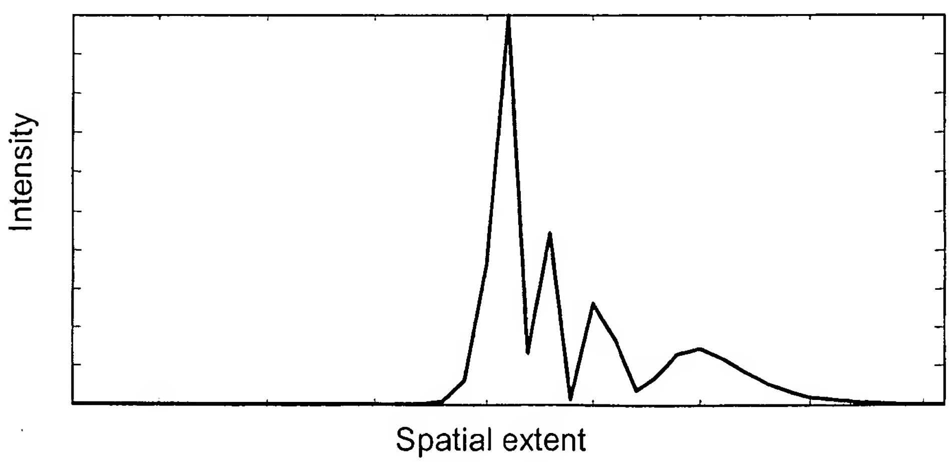


FIG. 17. PSF of a WFC, cubic phase system for zero misfocus ($\psi = 0$).

FIG. 17 shows the PSF of a WFC, cubic phase system (without post-processing) for zero misfocus ($\psi = 0$). FIG. 17 corresponds to Fig. 20 of the application as filed, except for the choice of horizontal and vertical scales, and resolution of the data plotted. In comparing the PSF

shown in FIG. 17 with that of the unmodified, traditional imaging system (FIG. 5), the stopped down system (FIG. 8(A)) and the stepped phase system (FIG. 10(A)), it may be observed that the functional form of the PSF of the WFC system is quite different from those of the unmodified, traditional imaging system, the stopped down system and the stepped phase system. That is, the PSF of the WFC system, without post-processing, is more asymmetric in comparison to *sinc*-squared forms of the PSFs of the earlier discussed systems. In other words, the functional form of the PSFs in a WFC imaging system is different from the functional form (i.e., *sinc*-squared) common to the earlier discussed unmodified, traditional imaging system, the stopped down system and the stepped phase system. In fact, after post-processing, the PSFs of a WFC imaging system remain consistent for a range wide misfocus values, as indicated in Figures 21-23 of the application as filed.

Another way to compare the PSF of the WFC system with those of the traditional imaging system is to compare the images of point sources produced by the different systems for different values of misfocus. The images of point sources, as shown in FIGS. 13(a)-13(i), yield a visual comparison of the PSFs of the unmodified, traditional imaging system with the PSFs of the WFC system, without and with post-processing. For example, it may be seen that the images of point sources of the unmodified, traditional microscope (as shown in FIGS. 13(a)-13(c)) appear more distorted with increased misfocus. That is, the image of the point source becomes increasingly more distorted as the system is brought further out of focus from the in-focus image of FIG. 13(a) to the more out-of-focus images of FIGS. 13(b) and 13(c). However, the WFC system, without post-processing, (as shown in FIGS. 13(d)-13(f)) produces images of the point source that are asymmetric in a consistent manner regardless of misfocus; that is, FIGS. 13(d)-13(f) are all asymmetric but visually similar. Consequently, a single digital filter, generated with *a priori* knowledge of the optical system and phase function but without knowledge of the misfocus parameter value, may be used to restore all of the WFC images in FIGS. 13(d)-13(f) to images of the point source, as shown in FIGS. 13(g)-13(i). Such recovery of the point source images regardless of misfocus would not be possible with any one of the unmodified, traditional imaging, the stopped down, and the stepped phase systems.

Related Proceedings Appendix

(THIS PAGE INTENTIONALLY LEFT BLANK)